ELECTRICITY FOR YOUNG PEOPLE

TUDOR JENKS

GUGLIELMO MARCONI — THOMAS A. EDISON
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ALEXANDER GRAHAM BELL — LORD KELVIN

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BY

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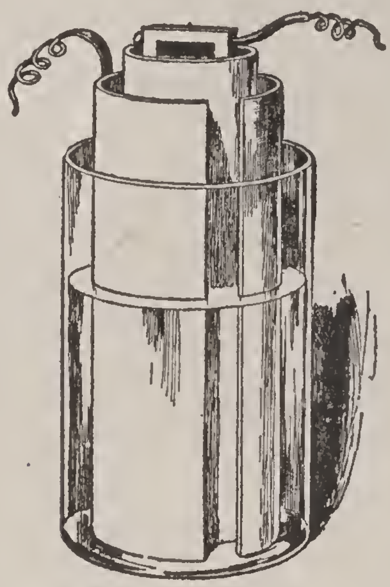

New York

Frederick A. Stokes Company

Publishers

Preface

THIS is the story of electricity told so that those who are not especially skilled in the science, who are not electricians, mathematicians, or experts of any kind, can understand how mankind came to find out a new power in the world, how they learned its ways, how they invented means of controlling it.

Beginning with the first wonder of the ancients over the lightning and the thunder, the magic doings of amber, the mysterious power of the lodestones or natural magnets, we shall see the steps by which, finding out a little here, a little there, wise thinkers and patient workers were able to do more and more with the new force. We shall see the unaccountable ways of an unknown power become at first the study of men of the deeper sciences; then practical workers will make use of what the men of science have learned, until in these early days of the twentieth century, the strange genie, electricity, is so far tamed as to be our daily friend and helper, tractable when rightly guarded.

Once become man's servant, electricity is seen to be capable of almost any kind of work, and tends to replace all other helpers, or to give them better methods.

We shall make some acquaintance with the men to whom all this is due, remembering how much their work has meant to us, and under what difficulties it was done.

We shall not feel bound to go deeply into all the questions and problems and speculations these inventors and discoverers toiled over. Many of them merely represent long travels in false paths, when the men were following up wrong guesses. But we shall try to share the pleasure in the great discoveries, to go over again the old paths that were in the right direction, and by twists and turns led out of the dark jungle of ignorance.

We shall try to learn enough to understand how, by the use of electricity, we at our will gain power, heat, light, sound; how we extend our control over the earth and the living things upon and beneath its surface, how we save time by easier and quicker methods of sending intelligence, and overcome space by better, swifter, and less cumbrous means of travel and transportation.

In so great a science there is work for unnumbered students throughout their lifetimes; and our effort will be only to become so acquainted with electricity that we may consider it as a daily friend and helper, one that must do man's will, rather than a strange spirit of enormous and unknown powers, following a mysterious will of its own.

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CHAPTER I

HOW MEN FIRST KNEW ELECTRICITY

It is hard for us to think back to the early times. If a grown man should try to get rid of all he had learned and thought, so that his mind would become like that of a very young child, he would be undertaking a similar task to that which we have to perform when we seek to put ourselves in the places of the men of old. We cannot feel as they did, or know so little; we can only in an imperfect way imagine their state of mind, just as in reading a story we "make believe" and so become ourselves part of it.

And this faculty of "making believe" is not only necessary in looking backward. It is also even more important in looking forward. Used toward the past, it is the faculty that makes history; used toward the future, it is the faculty that makes inventions.

Perhaps you will have more respect for it if we give it a dignified name such as men of science have adopted, and call this faculty "constructive imagination." By that name the world recognizes this faculty as that by which mankind has worked its way out of a condition little better than that of the chimpanzees or the orang-outans, through the barbarism of stone tools and implements, the savagery of the

wandering life and of continual warfare to the days of a bettering civilization whose end we cannot see.

Just as this power of "constructive imagination" has brought us civilization, so it has given us, and is giving us our sciences. For science is knowledge put in order.

The story of every science must be in many respects the same. It is no more than the gathering of facts, the putting of knowledge in order for use, and then using it. At first, before there is any large body of facts, there is no possibility of any science, rightly so called. And we shall find it so in the science of electricity. It begins only after a certain amount of knowledge, a number of facts are known and arranged.

Probably no one needs to be told that the first of the facts in nature that made man acquainted with electricity was the thunder-storm. Even the dullest savage, the most inattentive barbarian, the least observant child, could not fail to know there was something unusual at work in nature's shop when the white thunder-heads mounted upward on the horizon, like strange gods peering over the earth's rim; when the heavens darkened, the winds raged, the clouds split open, flame shot forth, and the thunder pealed, rolled, and died away in long reverberations. These were *facts* no man could help observing — facts that even the savage mind must seek to explain by its best reasoning — the best use of its faculty of "making-believe," the constructive imagination.

And the savage mind did the best it could. The savages knew power and force mainly as that of other men and beasts they could see, and by these they had explained many things. What they did not under-

stand they explained by stories of men and beasts they could not see — imagined gods and monsters. They knew that their warriors and kings roared and struck when angry, and so they explained the thunder and the lightning as the expression of the wrath of the unseen gods, whose voices stunned their ears, and whose angry blows blasted trees or slew beasts and men. Such was the beginning of electric "science," and such for ages upon ages it remained.

When the electric fire was destructive, it was a sign of wrath and fury; when it was harmless flame, it was thought to be a sign of the favour or special notice of the gods.

When mankind began to make records in clay, upon leaves, and in stone carving, they left us stories of this belief. In the early mythologies we find thunder and lightning assigned to one god or another. Thunder is the Hammer of Thor, the Scandinavian god; it is the Voice of God to the Babylonians and Chaldeans, and to the ancient Hebrews, as we see in the Bible most poetically in the Book of Job, in the Psalms, and in 2 Samuel. Thus, in the last, David sings: "The Lord thundered from heaven, and the most High uttered his voice. And he sent out arrows and scattered them; lightning, and discomfited them." This same metaphor — where the lightning is spoken of as the arrows of the Lord — is in the one hundred and forty-fourth Psalm; and even if it is used poetically, the figure shows that in earlier times the lightning was believed to be the weapon and the thunder the voice of the gods.

The same belief is in the mythology of the Romans, the Greeks and the Etruscans, as, indeed, it would be,

for these peoples also derived their religious and scientific ideas from the peoples of the East. The god Jupiter, as lord of the heavens, the upper air, was the wielder of the "thunder-bolts," and in statues is shown as grasping them in his hands. Zeus, his Greek forerunner, also had power over the arrows of the skies, and spoke in the voice of the thunder. One story of the death of Ajax Oileüs, though not that told by Homer, tells how Athena borrows from Zeus the thunderbolts that wreck the hero's vessel.

That the thunderbolts were thought to be forged by the Cyclopses in a volcano only shows that the fiery flames of the mountain and its rumbling were thought to be like the flashes of the lightning and the rolling thunder. That the thunder was thought to signify the will of the gods, and that those who were struck by lightning and uninjured were thought mercifully spared as favourites of the gods, are only natural outcomes of the general belief. Of more importance are the stories that the ancients believed lightning could be averted by various devices. The Persians are said to have thrust their swords into the earth, during thunder-storms — as a sort of protection; probably because they had seen swords apparently attract lightning. The Greeks put nails into birds' nests to protect the eggs, and the Romans laid bloody axes in a row as protection against lightning. These are more likely to have been superstitious than scientific devices. The Thracians shot arrows against the thunder-clouds, which looks like an attempt to scare away bad spirits.

Once lightning was recognized as a supernatural weapon, its symbol in art — a zigzag line — came to mean force or power, and the use of it on military

standards, on shields or armour became common. The Twelfth Roman Legion under the Emperor Marcus Aurelius bore this symbol upon its shields, and either from the ornament or from a certain battle in which it was unexpectedly victorious, gained the name of "The Thundering Legion." Being in a deep defile, in the year 174 A. D., they were so closely besieged by their enemies that they could neither break their way out nor get water to drink. Of both troubles they were relieved by a furious thunder-storm which refreshed them, and threw the besiegers into confusion.

Some authorities claim that the name of the legion had been borne by it before the date of the battle; but, in any event, the battle, the device, and the name have come down to us together; and with them comes the story that the storm was the result of the prayers of Christian soldiers under the Roman standards.

Throughout ancient history the thunder rolls, and the lightning flashes always in an atmosphere of mystery and superstition — and, as in the legendary disappearance of Romulus in a thunder-storm, is a sign of the direct intervention of the gods. And so long as anything is accounted for in that way, there can be no scientific knowledge of it, since its causes and laws will be sought by trying to arrive at the reason for the action of the supernatural powers — their wrath or their benevolence. Thus men's attention will be directed to whether good or ill-fortune follows after it has thundered on the right or the left, the first being thought an omen of the gods' favour, or to finding some reason why this or that great man was killed by lightning — as was the father of Pompey the Great, —

or to making others believe they have the power to control the lightning, as was done by the women in ancient Thessaly, and by various sorcerers.

That such claims were seriously believed we may know from the existence of a solemn argument as late as the ninth century, wherein a bishop attempted to prove the impossibility that magicians could exercise the powers they claimed over thunder-storms. Again, it was, even to the times of Shakespeare, a belief that witches could raise storms — though to mention this is to go too far ahead of our story.

Undoubtedly some of the claims were merely the work of impostors such as the old Greek king of Elis, Salmoneus, who, wishing his subjects to regard him as a god, drove a chariot over a brazen bridge to imitate thunder, and hurled lighted torches about, to seem like thunderbolts. Jupiter, either disgusted with the poor counterfeit or angered by the impudence of his understudy, is said to have slain the sham thunder-god with a real stroke of lightning — which might have been attracted, we may suppose, by the "brazen bridge," or the metal armour of this "little tin god on wheels."

The poet, Edmund Spenser, in giving the origin of the fairy-race speaks of one,

> "— Elfinor, who was in magic skilled ;
> He built by art, upon the glassy sea
> A bridge of brass, whose sound heaven's thunder seemed to be."

But this was no doubt an independent legend.

Besides seeing the power of the gods in the violent electric disturbance of the thunder-storm, the ancients saw in the milder forms of the same agency, signs of

the gods' good-will or their protective influence. In the legend of the Argonauts it is told that they were overtaken by a dangerous tempest, when Orpheus prayed for deliverance, and soon there appeared two harmless flames playing about the heads of Castor and Pollux, after which the storm subsided, and the sea was still. This old legend made the Great Twin Brethren the patron saints of sailors, and probably helped in the belief that the same electric light — since named the St. Elmo's Fire — was an omen of good to the ship upon which it appeared.

In the classic authors are frequent references to these lights of Castor and Pollux, as well as some to a *single* light, known as "Helena," and considered by at least one authority (Euripides) as lucky, too, though the general belief considered the single light to presage storm and wreck, especially if it came after the twin lights of the Brethren. The poet Horace, in his Ode to Augustus, as translated by Conington, celebrating the gods in turn, says of "Leda's Twins":

> "— Soon as gleam
> Their stars at sea,
> The lashed spray trickles from the steep,
> The wind sinks down, the storm-cloud flies,
> The threatening billow on the deep
> Obedient lies."

All these instances serve to show not only the attitude of mind the ancients held toward such forms of electricity as are most obvious, but they have some scientific value, as proving these appearances to have been noted, and, in a crude way, noted as being followed by certain results, more or less frequently.

Undoubtedly the ancients must have observed the Northern Lights — the Aurora Borealis. But not knowing what caused the appearance or wherein the brightness that was seen occasionally in the sky differed from other similar appearances — such as the light from shooting stars, and that from lightning below the horizon, or the so-called "heat lightning," it is impossible to be sure that any given account is really speaking of the aurora and not of some other light.

Besides, owing to superstition — science's greatest enemy — the polar lights when seen were (in Ireland) described as a "rain of blood," or as "burning spears" (in London). Then, too, the northern and southern latitudes show the lights most frequently, while the observers who could have made record of such phenomena were dwellers in the middle latitudes, about the Mediterranean or in the northern regions of Africa. Altogether it is not strange that the earliest definite accounts of the aurora are not much older than the sixteenth century — though a few indefinite observations date back to the years 502, 688, and to the eleventh and twelfth centuries, while Pliny among the Romans and Aristotle among the Greeks gave some description of these lights in the sky, without attempting any explanation.

The action taken by the ancients, even so late as in Rome's days of supremacy, shows plainly that their feeling toward these marvels was altogether superstitious; for where lightning struck, it was customary to set up altars, erect enclosures, or make sacrifices; while any "fragments of the thunderbolt" (results of the lightning's action) were "carefully buried, lest any

person should be polluted by touching them." Among the Greeks, it was the custom to hiss or whistle to avert the lightning's evil influences, as we learn from Aristophanes.

And, unfortunately, where there is superstition, there is a likelihood of "constructive imagination" of the wrong sort. Believing that the thunder and lightning should accompany great events, it is easy to assert that they did so. Thus we are told of a flash of lightning that struck the Roman capital when Julius Cæsar was slain, and "struck away the first letter of the name of the prince" from the inscription on his statues — a truly remarkable tale!

But history is full of these marvels, and each has its interpretation. From the observations of modern scientific observers we may gather stories of electrical flamings, glowings, and lightning strokes that will parallel any of the *facts* recorded in ancient annals, the chief difference being that the ancients were credulous and inventive enough to make their stories the most striking and poetical.

CHAPTER II

FIRST KNOWLEDGE OF ELECTRIC ATTRACTION AND REPULSION

In the times when only the most striking appearances were observed, it might satisfy mankind to see in thunder and in lightning, the immediate power of their gods. They were simply the amazed and wondering observers who trembled and uttered a prayer, when threatened by such terrors as are described so grandly by the poet and prophet Isaiah: "And the Lord shall cause his glorious voice to be heard, and shall shew the lighting down of his arm, with the indignation of his anger, and the flame of a devouring fire, the scattering and tempest and hailstones."

But though long centuries were to pass before men dared to question the thunder-cloud, to gaze steadfastly upon the flash of its fire, there were other forms of electric action so trivial in their effects as to excite curiosity rather than awe, and to incline the mind to experiment rather than to reverent prayer.

There was discovered upon various coasts of the sea a certain curious substance. It was light, transparent, tough, and inflammable, generally yellow. It looked as if it had once been liquid. What it was, the ancients did not know. But they followed their usual custom of accounting for it by a sort of fairy-story. Phaëthon had tried to drive the chariot of his father the Sun. Coming out of his course, he had scorched the earth, dried up oceans, and darkened the

faces of the Ethiopians. Jupiter, to save the earth, hurled a thunderbolt with such good aim as to strike the son of Phœbus from his chariot into the River Po.

Then the Heliades, sisters of the reckless charioteer, through the pity of the gods became poplar trees and wept tears that were changed into the strange substance found on the coasts of various countries, and in some places dug out of the earth. Now *Ἤλεκτωρ* (Alector) "the shining one," is a Greek name for the sun-god, and "electron," the shining thing, was the name given to these solid tears — and here is the romantic origin of the word "electricity" — an origin that connects it most appropriately with the shining brightness of the sun.

But the tears of the Sun-maidens are known to us by another name. We call them "amber," a word that comes to us, most dictionaries say, from the Arabic *'anbar*, the ambergris; but I believe the lexicographer Richardson is right in agreeing with some German authorities who trace it from their own verb *brennen*, to burn, *anbrennen*, — the thing that will burn. This seems likely, partly because *ambergris* is only "gray amber," in French, and that would indicate that amber was known before ambergris to those who adopted the two words.

At all events, the substance amber was known and prized even earlier than Homer's days, some twenty-eight centuries ago, for a necklace of gold and amber is mentioned as being among jewelry brought by a Phœnician trader to the home of Eumæus, the old slave of Odysseus, for the purpose of keeping the women of the household busy while Eumæus was stolen by his Phœnician nurse. Amber is known to have been used

even in prehistoric times, and was traded in by the Phœnician merchants. It was inlaid in wood, and it decorated weapons or shields. But this same name, electron, was given by the Greeks to several substances, and especially to some metallic alloys; so some of the mentions of electron may not refer to amber. We learn from Pliny that by the Syrian women amber was called "harpaga," or "the clutcher," a name we see given also to the harpies.

Park Benjamin believes this name arose from the use of amber spindles in spinning thread. As the spindles whirled, rubbing against the women's garments, the amber was seen to draw to itself bits of thread, the fringe of a garment, or particles from the floor. This "clutching" must have seemed a magical power to the spinsters, and won for the amber its curious name.

Among the properties for which amber was — and still is — valued, is its capacity for taking a high polish. For a time after being rubbed, as the ancients soon discovered, the amber showed a strange property — the same property noticed by the Syrian women. It drew to itself chaff, straw, bits of string; these remained clinging for a time. Then, after clinging a while, they would be repelled; but the ancients seem not to have mentioned this repulsion. Even the attraction is rarely referred to in early times. The first written record of this is said to be found in the writings of Aristotle concerning Thales of Miletus, regarded as the chief of the Seven Wise Men of Greece. Thales lived about the time of Æsop and of Nebuchadnezzar and it is somewhat doubtful whether he was referring to the attraction of amber or of the

lodestone, in the tradition recorded by Aristotle. All we know of the matter is that Thales is said to have believed that the action of the amber or the lodestone (natural magnet) indicated the existence of a soul in these substances. By this statement the wise old philosopher probably meant only that it had "a power of its own" not drawn from outside, for to a philosopher this would be to have a soul.

It is not to be wondered at that there is some confusion in regard to whether the lodestone or the rubbed amber was referred to by Thales, for the attractive properties of the two would be classed together long ages before the real connection between the two was even suspected. The lodestone had even in the time of Thales, more than six centuries before Christ, been known for possibly two thousand years, if we may accept the traditions of the Chinese, wherein there is an account of an emperor's constructing a chariot for indicating the four cardinal points; but this may be merely some old story with a modern revision applying it closely to facts known later. Humboldt in his "Cosmos" tells of Chinese caravans being guided by a little revolving figure made to point always in the same direction by means of a natural magnet.

It seems doubtful that the magnetic needle was known in any but the crudest way even to the Chinese before they acquired the knowledge from some of the Western nations, though it is very likely they knew something of the natural magnet or "lodestone" even before the Greeks.

And this name "lodestone" is a curious one. The first syllable, or first word, "*lode*," meant "way"

or course, and is connected with our verb *lead*. The term still survives in mining. But lodestone means the stone that points the way, and this seems to indicate a very early connection between the magnetic ore and the compass-needle. The Greeks gave us the word "magnet," probably from the place where the ore was found, near the town Magnesia, in Lydia; but they had an earlier name — the Heraclean Stone, either from another town also in Lydia named Heracleia, or from the name of Herakles — the Greek form of Hercules. But the whole subject is a debatable one, and not now worth many words.

More important it is to tell what they knew about "The Stone," as Aristotle calls it. That it would attract iron, and hold it, is about the sum of ancient knowledge until the time of the poet Lucretius who left us a scientific sort of poem on "The Nature of Things."

Lucretius, born nearly a hundred years before Christ, set forth in a pure, forceful way, and with honesty of purpose, the best views of his time, as gathered from the Greek philosophers, upon the questions of man's relation to nature — that is, upon scientific subjects, and their relation to religious views. He gives us in brief a summary of the philosophy of the time. He was well read, and likely to give accurate views.

As to the magnet, he tells us the origin of the name from Magneta (magnesia), records its power to "*ducere ferrum*," or attract iron; and declares that "men wonder at this stone," since it is able to support a chain of hanging rings — an important observation since it is the earliest record of the fact that magnetism

acts through one piece of iron upon another, pervading a series. He also speaks of the iron sometimes seeking the magnet-stone, and then fleeing from it — which, in view of what they knew, seems a difficult thing to explain. There seems no likelihood that the attraction and repulsion of the poles of magnets were known to the Romans at that early day; and yet Lucretius speaks plainly of the jumping about of iron filings in a brass vase when the lodestone was put beneath the vase, in a way that is explained only by assuming he had seen some experiments he had not thoroughly understood — experiments such as we shall speak of later.

The whole knowledge of the ancient world was, however, no more than a small number of misunderstood and unstudied facts, and aimless experiments repeated over and over merely from curiosity or for amusement. We have seen Thales explaining the magnet by saying it had a soul; and we have omitted to mention the Roman poet Claudian, who saw in iron a food for which the magnet is hungry. Lucretius, though a student and thinker, could say only that in the magnet and extending beyond it was a sort of vacuum, as the French author Guillemin says in his "Electricity and Magnetism," adding, "There is nothing, however, in all this worth discussing."

In this we agree, since so queer a fact as the attraction of the lodestone would be likely to find notice in every ancient work upon nature or physics, and yet the remarks upon it could have value only to the student of the past, to the historian rather than to the student of electrical science.

And what is said of the lodestone and magnet is

equally true of the mariner's compass. There are, besides the usual Chinese legends, many stories more or less doubtful of its employment down to the twelfth century, at which period there is a reference by a cardinal in his "History of Jerusalem" to the use of the compass by mariners. Other references tell us of the "rubbed needle" used by sailors to guide them. These early needles were put into straw, mounted on cork, or suspended on a point like modern compass needles. The best authenticated story tells of the invention of the compass by an Italian, a Neapolitan of the fourteenth century. This was about 1320, and the man's name is given as Flavio Gioia. Columbus, in his voyage of discovery, noted a fact, already vaguely known, that the compass varied from the true north; but he added the important observation that this deviation was different in different localities; and about five years later Sebastian Cabot noted that the deviation was regular for the same needle in the same localities — both of these being truly scientific observations. As to Cabot's, however, we now know that the needle has daily, yearly, and periodic variations, even in the same locations in certain parts of the ocean reached by him, so that his observation was far from being an exact statement.

As the needle was longer known, facts about it accumulated, and being *written*, began to be put into form, and to grow into a science. In 1576, Norman, a London optician, found out that a needle hung freely at its centre of gravity, not only swung around an axis until an end pointed northward; but also that the same end dipped so as to be directed downward toward the earth. He was angry that he could not

easily balance the needles he made, and by the aid of "certain learned and expert men, his friends" experimented until he discovered this dipping to be a property of the needles.

Of course while these scientific observations were being collected, the men of imagination were likewise busy in wonder tales of the magical properties and doings of the lodestone. Thus there is an old story that Ptolemy Philadelphus with his architect had a pretty plan of building an arch of lodestones so that it would suspend in air an iron statue — a good idea providing it had been easy to exactly arrange matters so the statue would neither rise nor fall. St. Augustine tells of the same device as being carried out by certain "pagan priests" — not suspecting he is crediting them with what would be a miracle of science; and a legend tells of Mahomet's coffin being so suspended.

Let any one inclined to believe any of these stories buy two magnets, and then, laying a needle on a smooth piece of paper between them, so adjust the magnets that it would be moved to one except for the attraction of the other. Theoretically the experiment should succeed. Practically it won't.

Pliny tells the story of Ptolemy Philadelphus, and he also records the report that there existed "near the Indus" two mountains, one of which attracts iron and the other repels it. It is part of the same veracious story that travellers with nails in their shoes cannot raise them from the ground when near one mountain, nor touch their soles to the other. And in the "Arabian Nights" the "Third Royal Medicant" tells of a mountain of lodestone that attracted the iron-bolted vessel, extracted the bolts, and thus caused her

wreck; but in this mountain there is some magical property caused by a strange statue on its top.

From all this it is easy to see that there was as yet nothing worthy of the name of a science of electricity and magnetism, though a few bits of accurate knowledge were in print and accessible to students.

One other sort of electric action was known to the ancients in the same imperfect fashion. Besides the thunder-storm, the St. Elmo lights, the auroral light, the rubbed amber (to which should be added a few other substances in which the same property had been observed, as "lyncurium"— probably tourmaline — mentioned by Theophrastus, disciple of Aristotle 321 B. C.), the lodestone and the compass, a strange property was observed in certain animals.

In the Mediterranean is found a flat fish known as the torpedo. The name is an ancient one, given because it had been discovered that this fish had the power of dealing certain shocks that made men or other animals benumbed or *torpid*. This fish, also called "cramp-fish" and "electric-ray," is at times five feet in length, and weighs as much as seventy-five pounds. This fish was known also to the Romans, being often painted on the walls of the buried city Herculaneum. Dioscorides, a physician, who lived in the time of Antony and Cleopatra, declares that, touched, it cured headaches, and in later days it was used to cure gout and rheumatism — the oldest use of electricity in medicine.

The electric eel of Africa (and warmer parts of America), also over five feet in length, is able to give a very powerful shock, and there is still a third electric animal called the electric silurus, also found in African waters.

That all these were known to the ancients is undoubtedly true; but in a world filled with things they did not in the least attempt to explain, there was no reason why the peculiar power of these creatures should have set men upon especial inquiry. The fact that men or horses were violently affected when brought into contact with them was known, remarked as a mystery, but one no greater than ten thousand others. The ancients were like children standing in a great laboratory or factory. They saw things happen, were amused, or interested, or filled with wonder. They told one another about them, may have made some vague guesses — and there the matter rested — waiting for the birth of a *scientific method*. For this we shall have to come down the ages to the times of Queen Elizabeth in England. Now the author of "The England of Shakespeare," Edwin Goadby, begins his chapter on "Science and Superstition" by the sentence, "The English of the Elizabethan age were an eminently unscientific people"; and he points out that the learned men of the time were likely to be regarded as magicians and sorcerers, while the pretenders to magic were many, and belief in alchemy (the power to change one metal into another, as lead into gold), in astrology, or the reading of men's destinies in the stars, was nearly universal.

Bacon was perhaps the most learned and one of the most sensible men of his time, and yet he thought little of Giordano Bruno's theory that the earth went round the sun, was inclined to think mathematics not a "practical" study — as, indeed, it may not have been in his time—was sceptical of the value of the telescope in astronomy, and drew up a list of things tending to

ensure long life that is a mixture of sense and nonsense.

Yet it is in this age we shall find the beginnings of electric science. For despite the rubbish that still clogged men's brains, books were becoming abundant and comparatively cheap; there was some rest from religious wars and squabbling, so that men might give their time to study and experiment; and though the foundations of scientific method can be traced in their beginnings to Roger Bacon, and even earlier, and were added to by such men as Copernicus, Da Vinci, Tycho Brahé, and others, so far as electric science is concerned, its beginning is with Dr. William Gilbert.

CHAPTER III

DR. GILBERT OF COLCHESTER

In reading the history of man's progress in science, it often seems that the successful steps were more the result of accident than of studious intention. Without apparent reason, some man will turn his attention to a given subject, and, without evident advantage over his fellow men, will advance an art or a science by enormous steps.

So true is this that it often seems to us as if it was more a result of men's attention being devoted to a subject than to any real advance in knowledge that progress is due.

But it is probable that this conclusion is a mistake. We shall find, on looking more closely into any science, that each step usually depends upon the preceding one, and until the preceding one be taken, no intellect can point out the true path of progress.

In the history of attempts to navigate the air, we find that every improvement in engines making them stronger or lighter helps those who try to make flying-machines. In our own day, the manufacture of auto-cars seems to depend directly upon the ability to make light and powerful engines. In the making of optical instruments, such as telescopes and microscopes, it is the glassmaker who furnishes the material that makes more effective lenses possible.

It may be that the same explanation will apply to the enormous advance in knowledge of magnetism that

was brought about by the studies of one man during the reign of Queen Elizabeth. But, in the absence of such an explanation, it certainly is a marvellous happening that one student, without especial advantages over his fellows should by himself have discovered all the main principles that underlie magnetic action, so that his book, published more than three hundred years ago, contains, according to Dr. Whewell, really the essence of all the knowledge of magnetism to be found in text-books for long years after his time, and until the investigations of such philosophers as Oersted and Faraday. It is true that in our own time new theories have been propounded, but even if these be regarded as entirely established, all honour is due Gilbert for the accurate and complete nature of his treatise upon magnetism. The story of his labours cannot but be an interesting one.

It is impossible to give the exact date of this man's birth, since there is a disagreement between the inscription upon the portrait he gave to Oxford and that upon his monument in the chancel of the Church of the Holy Trinity of his native place, Colchester. The monument declares that he died in 1603, at sixty-three years of age, whereas the portrait declares him to be in his forty-eighth year in the year 1591 — three years younger than he is made by the monumental inscription. As Gilbert must have seen the inscription upon his portrait, it seems that it is more likely to be correct, and we may explain the disagreement by supposing a blunder to have been made between himself and his brother, who bore the same name, William Gilbert, and who afterward edited some of his work.

Born in 1543, we may say, about fifty miles northeast of London, in a house which has been preserved to our own time, he received a good education in the grammar-school of his native town, and at Cambridge took his final degree as doctor, in 1569, when Shakespeare was five years old, and Francis Bacon eight.

A trip to the Continent brought him the acquaintance of distinguished scholars, and when he began practice in England his success was rapid, so that we find him president of the College of Physicians in 1600 when Shakespeare was at the height of his career, and physician to the Queen not many years later. To Elizabeth's favour, also, he owed two other pieces of good fortune that may have been the special helps that brought him fame. In the first place, the Queen had him come to court to live, which gave him a home rent-free, and she also settled on him a pension, leaving him to give his time to scientific studies.

In an article in *The Popular Science Monthly*, by Brother Potamian, professor of physics in Manhattan College, New York City, it is pointed out that Gilbert owed his success greatly to his insisting upon testing the truth of doctrines he had heard, rather than in accepting them upon the authority of others. He was, as Brother Potamian declares, the natural successor of Albertus Magnus and Friar Bacon, both of whom made their own experiments, thus asking their own questions of nature; and both did work that formed a solid foundation for the labours of their followers.

Thus, when it was told to Dr. Gilbert that the Italian philosopher, Baptista Porta, asserted that a piece of iron "rubbed with a diamond turns to the

north," he at once put the assertion to the test. Nor was he satisfied with only one trial, for he experimented with seventy-five diamonds in the presence of many witnesses, using different pieces of iron, and bits of wire, floating them on corks, yet without finding that they would point to the north.

Of course the modern philosopher knows that Porta's declaration referred not to a *diamond*, but to a lodestone. In the Middle Ages the natural magnet or lodestone was called "adamant," a name applied to any very hard substance, and meaning "unconquerable." The diamond also was called adamant, because of its hardness; therefore it was natural for Porta to give to the lodestone a name which the Englishman could refer only to the diamond. Porta's statement was correct, but was misunderstood. For, indeed, Porta himself was a man of science, and imagination, a most prolific writer, and founder of a scientific academy. He had some notion of the possibility of the telegraph, describing how two magnets *might* be made to turn to the same points in concert; but he of course had no idea how this was to be brought about practically.

Though these experiments seemed to come to nothing, they show us how carefully Dr. Gilbert tried the truth of what he heard asserted.

And this, as the author of the article already quoted points out, was about a score of years before Francis Bacon wrote the philosophical books that have led some to credit him with introducing the experimental method of arriving at scientific truth.

The account of Gilbert's years of investigation is contained in his treatise on magnetism, the Latin

name of which may be translated into "About the Magnet and Magnetic Bodies, and about the great Magnet, the Earth." This book came out in 1600, and the third part of the title set forth Gilbert's greatest discovery, namely, that the globe on which we live is itself magnetic and may be looked upon as a big spherical magnet. When he had found this out, it was seen that this fact explained not only the polar pointing of the needle, but also its dipping, or pointing toward the center of the earth, as well as its varying from time to time in one direction or another.

This great work was the first in its field, and for very many years remained the only treatise of importance upon its subject. It was received by the learned men of the time with intense interest. Kepler, the great astronomer, Galileo, and others nearly as eminent, made his fame known among scholars everywhere. Francis Bacon is accused of jealousy toward Gilbert and of a wish to make little of his work, in writing that Gilbert "had attempted a general system upon the magnet, endeavouring to build a ship out of materials not sufficient to make the rowing-pins of a boat." He also said, with more humour than kindness, that Gilbert had so lost himself in his subject that "he had himself become a magnet!"

Edward Abbott, a fair-minded biographer of Bacon, excuses the philosopher's faint praise of Gilbert's achievements by the suggestion that "to Francis Bacon, impatiently aspiring after vast and general conclusions, Gilbert's researches seemed petty and narrow."

But we must say, as to this, that Gilbert was practically following out precisely the method of science

Bacon was trying to establish — namely, learning the laws of nature by careful experiments, and then seeking ways to make the knowledge of those laws useful to men in their daily lives.

To-day some authorities regard Gilbert, rather than Bacon, as the true father of all experimental science; and this should be sufficient answer to Francis Bacon's belittlement of the painstaking experimenter. It would be kinder toward Bacon to believe that he thought Gilbert's experiments were not exhaustive — a belief finding some support from his remark about the scanty materials Gilbert accumulated. Others, like the Britannica, give the honour of founding experimental science to Robert Norman, as will be noted later. Yet the conclusions Gilbert drew were in the main correct, and that is the best praise of his method.

The second chapter of Gilbert's book was the first treatise on electricity, the first serious study of the matter. He advises the reader who wishes to repeat his experiments to make a little "rotating needle of any sort of metal particularly light and poised on a sharp point." Rubbing different substances, Gilbert brought each near his "versorium," or turning-needle, to find out whether it was electric. He soon found out that many substances when rubbed attract not only the needle, but everything else. There is also found, however, a number of substances that do not attract when rubbed, and he names the two "electrics" and "anelectrics," or non-electrics.

The word electric is used in its Latin form by Gilbert, as an adjective applying to bodies, to influence, to attraction, to motion, and so on; and he was the inventor of this use of the word. In all his investiga-

tions and reasonings upon them, the learned Elizabethan failed to hit upon certain very obvious facts. He did not find out that there were two sorts of bodies, one allowing electricity to pass through them, the other preventing its passage; that is, he did not find out that there were conductors and insulators.

The word *electricity* seems not to have been used by Gilbert, its first occurrence being in a work by Sir Thomas Browne, the well known physician and essayist, author of the "Religio Medici," and so on. He used it as a noun in his "Epidemica Pseudodoxia," in the year 1646. Such, at all events is the statement of Prof. Silvanus Thompson.

Gilbert tried some experiments to ascertain whether liquids were affected as solids are, and noticed that a drop of water is changed in shape when brought near to rubbed amber. He also discovered that smoke particles were attracted in the same way. It is strange that Gilbert overlooked the question of insulation and conduction, or preventing electric action and carrying it, for he made elaborate experiments as to how electrical bodies would act under all sorts of conditions, testing heated iron, glowing embers, and various kinds of flame, through which he learned that bodies in flame or very much rarefied were much less attracted to his "electrics." Lenses enabled him to try the effect of the sun's heat upon his electrics, but in this direction he found out nothing interesting.

But we may well wonder that he discovered so much instead of criticising him for missing facts now well known.

As to explaining the results which he observed, Gilbert of course had the defects of his time. He be-

lieved that electricity must be something extremely fine and delicate, but yet he thought it had substance, and declared: "It is probable that amber gives forth something peculiar that attracts the bodies." If we are disposed to criticise this ignorance of the old philosopher, we must remember that we are still guessing at the problem which bothered him, and are by no means sure that our own explanations are true.

We read from his notes, not only the story of his successes, but of his failures, and see him trying to learn the lessons taught by mistakes as well as by experiments that go right. And we need seek no better statement of Gilbert's work than that given by Brother Potamian, who says: "He founded and christened the science of electrics. He left it in its infancy, it is true, but with sufficient vitality to enable it to survive the neglect of years, until at last it was taken up and fondly cared for by our Franklins and Faradays."

Probably Brother Potamian does not mean to overlook the work of the many great men who preceded Franklin and Faraday but uses these names merely to signify all modern investigators.

Upon magnetism, Gilbert's observations were even more valuable than upon electricity. And though he thought no substance could be magnetized unless it contained iron, a conclusion now known to be incorrect, it was not to be expected that he should discover that nickel and cobalt were somewhat affected like iron, or that under the powerful electro-magnets other substances are influenced, as was known later.

Gilbert either by his own experiments, or by studying the works of others, came to possess all the mag-

netic science of the time. He speaks of poles of the magnet, naming them from those of the earth, names the line joining them the *axis*, and the line equally between them, the *equator*. He finds that magnetizing a needle makes it no heavier, as tested by the finest goldsmith's scales. He learns that a magnet cut in pieces yields small magnets, like that cut up in having poles and a field of force about each. He tries heat upon his magnets, and finds their properties weakened or destroyed. He puts substances between magnet and iron, and declares the magnetism is cut off (or absorbed) only by iron. The compass is tested by being put into boxes, and found to remain a compass still even in an iron box — though this would not have been so had his iron box been thick enough to prevent the influence of the earth's magnetism. It is now known that the iron (if sufficiently thick) would confine the magnetic lines of force, and so prevent a needle acting as a free compass needle.

And this leads us to his greatest discovery — his wonderful generalization, "*Magnus magnes ipse est globus terrestris*," meaning "the earthly globe itself is a great magnet." The fact is admitted to-day. The cause is not known with certainty, though various theories seem reasonable.

The value of the discovery was seen in its giving at once a reason for and an understanding of the action of compass needles, in pointing toward the poles, in dipping toward the center of the earth, and so on.

Gilbert added greatly to the facts known in his day, found out the laws that govern them, and explained the action of the needle by the magnetism of the earth.

Fuller in his "Worthies of England" gives Gilbert of Colchester a prominent place, and concludes quaintly and beautifully, "Mahomet's tomb at Mecca is said strangely to hang up, attracted by some invisible lodestone; but the memory of this doctor will never fall to the ground, which his incomparable book 'De Magnete' will support to eternity."

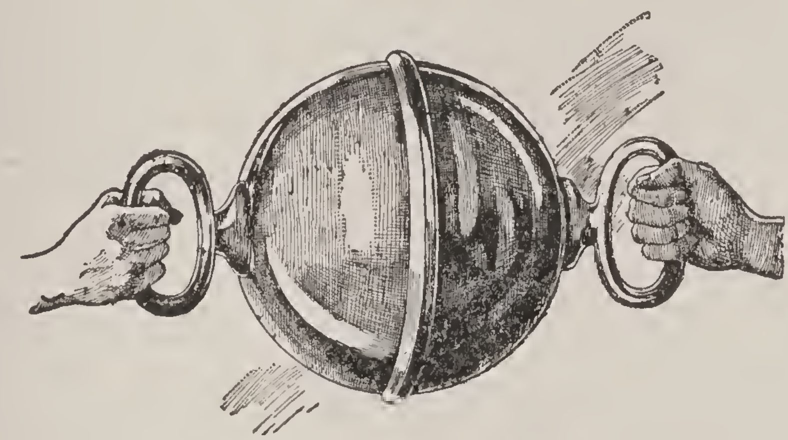
Robert Norman, who in 1576 discovered the magnetic dip, was, as heretofore hinted, possibly the true pioneer of inductive reasoning quite as much entitled to honour as either Bacon or Gilbert; for in speaking of scientific authors before his time, Norman declared, "I wish experience to be the leader of writers in those arts, and reason their rule in setting it down, that the followers be not led by them into errors."

Leaving Dr. Gilbert we part with the lonely experimenter, for about a year before his death was born Otto von Guericke, and von Guericke's life, 1602 to 1686, covers a time that introduces us to a number of men who contributed to the creation of electrical science, notably Sir Robert Boyle, Sir Isaac Newton and Francis Hawksbee. To these three Englishmen are due the discoveries, inventions and experiments that enabled a host of philosophers to work together in studying the laws of action of electricity.

CHAPTER IV

THE MAIN LAWS DISCOVERED

Otto von Guericke was born in Prussian Saxony, and after being educated as an engineer, and serving as such in the army, retired to Magdeburg, his native town, and was its burgomaster at the time it was captured and burned by Tilly, and 30,000 of its inhabitants out of 36,000 massacred. Guericke was then only twenty-nine years of age. About twenty years later, becoming interested in the study of natural philosophy, Guericke sought to produce a vacuum, and invented the air-pump. In 1651 he showed before the Emperor at Ratisbon, the "Magdeburg Hemispheres," two copper half-globes, which, when the air was



The "Magdeburg Hemispheres."

pumped out, could not be separated by fifteen horses pulling against an equal number. Yet, air being let in, they would fall apart.

Apparently the news of this experiment came to Robert Boyle, then about twenty-four. Son of the

Earl of Cork, he had been educated in England and gone abroad till 1644. Then, becoming rich by the Earl's death, he devoted himself to study. In 1654 he improved the air-pump, and made many experiments. He afterward became one of the earliest members of the Royal Society (founded in 1660), and discovered certain facts in electricity. Boyle found out that amber retains its electricity, that a body need not necessarily be smooth to be electrically excited, and that a cake of resin, and certain other substances were "electrics." He also discovered that if the "electric" body was left movable, it would be attracted, as well as attract. He reported these experiments to the Royal Society, and made up a theory to account for them, and for magnetism, calling the latter an "effluvium," or outflow of the magnet. This of course explained nothing, but it helped by giving a way of thinking about the magnet's action.

Not long afterward, whether knowing of Boyle's discovery about the resinous cake or not, Guericke made a ball of sulphur (one of the *electrics* Gilbert had mentioned) and caused it to turn while being rubbed by the hands. This was the first electrical machine, and came directly from the discoveries of Gilbert.

With this machine Guericke was able to show a stronger action, and thus to perform experiments more effectively. And with the greater action came a new discovery. When the sulphur was turned and rubbed, Guericke noted a feeble glow of light, — which was the first dawn of the electric light upon mankind.

By means of the same machine he found out that the electric action or "virtue," would act "through a linen thread an ell or more long, and then attract

something." Here was an experiment that seemed to show electricity to be like magnetism, in acting through one body upon another.

Meanwhile two other workers in natural philosophy were trying some of the new experiments. Isaac Newton, born in 1642, had been allowed to browse through the little library of an apothecary, and had, though a farmer's son, and left poor with a widowed mother, shown so much talent for mathematics and philosophy that he was sent to Cambridge, graduating in 1665. Within three or four years, the fall of the apple (if we may trust the story for which Voltaire is responsible) had set him on the track that led to the discovery of the law by which the heavenly bodies are governed in their flights through space. Besides mathematics, and the laws of optics, Newton experimented with electricity, and constructed a machine like Guericke's, except that he used a *glass* globe, finding it better than sulphur.

It is said that this improvement was probably due to Newton, but another claimant for the honour is Francis Hawksbee. The date of Hawksbee's birth is not given; but it is known that he made many experiments on light and on electrified bodies, discovering among other things that if quicksilver was put into a receiver or glass ball from which the air had been almost pumped out, upon the air being allowed to force itself in again, the receiver would appear filled with light that lasted until about half the air had reëntered the receiver. This experiment seems to us the first hint of the kind of electric light that is now produced by sending electric waves through glass tubes from which the air has been almost exhausted. Hawksbee was a mem-

ber of the Royal Society in 1705, and Newton had been a member since 1672. A son of Hawksbee of the same name, became Clerk and "housekeeper" of the society, and was, like his father, noted for his devotion to electric science. Their writings did much to interest learned men in the experiments made by the most distinguished scientific men in England, for it was the duty of the "Clerk" to correspond with scientific men of the Continent, acquainting them with the work of the Royal Society. Besides this work, the members began a museum, which afterward was turned over to the British Museum.

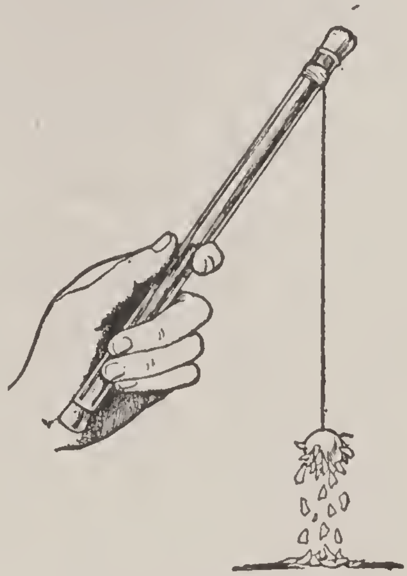
The formation of such a body, and its progress under the patronage of the King, Charles II, shows that *systematic* study of science had begun, replacing the singlé-handed investigations of so-called "magicians" and secluded philosophers, who began their study of the world by retiring from it. Similar societies had been formed in various countries before, but the time was hardly ripe for them, as scientific learning was not yet sufficiently general.

The beginning of the eighteenth century saw the rise of a new spirit. Frederic Harrison says that in "philosophy, science, in mental versatility, the eighteenth century has hardly any equal in the ages." . . . "It organized into science physics, chemistry, . . . electricity." It was the century in which men first worked together *knowingly* for the common benefit — not "the age of the lonely thinkers in their studies"; and the science of electricity was taken up seriously and in an orderly way by the able thinkers and workers in many lands.

One of the earliest of these was Stephen Gray, an

Englishman, who after the researches of Hawksbee was the first in twenty years to make electricity a special object of study. Sir Isaac Newton had brought other subjects more into vogue, by his remarkable discoveries. Gray was poor, but was by ingenuity able to make use of the commonest things to carry on his experiments, using, as Park Benjamin says, "fishing-rods, canes, the kitchen poker, cabbages, and pieces of brick," buying only his glass tubes and pieces of silk.

Gray discovered that there were conductors of electricity and also non-conductors. His discovery came from his having a glass tube with a cork in each end, which on being rubbed attracted light substances. The substances were attracted not only to the glass but to the corks, — which, not having been rubbed, must have gained their electric power from the glass. Then he tried putting various other substances in place of the corks, and seeing which would become electrified. Gray found that rubbing electrified *all* substances, but that the influence escaped from some of them, the metallic substances, for example, unless they were prevented from parting with it. He hung a metallic ball by threads to a rubbed glass tube, and found that if hung by some threads it became electrified; but if hung by others it remained unaffected — that is, did not attract the bits of paper by which he tested it.



GRAY'S DISCOVERY: The bits of paper were attracted only when the metal ball was hung to the rubbed rod by a *conductor*.

After making experiments with various threads he

found that some permitted electricity to pass to the ball, and these became known as *conductors.* The others, preventing it from passing, became known as *insulators*, for *insula* in Latin means an island, and these substances seem to cut off the ball or other substance from the electricity as water cuts off an island from the mainland.

Gray's next step was to see how far he could carry electricity along his conductors; and finding a hempen string a good *conductor*, and silk a good *insulator*, he hung a hemp cord by silk supporters and found he could transmit the electricity nearly 900 feet.

He tried many experiments to find out which substances would conduct electricity, and made lists of conductors and of insulators. The human body was found to be a good conductor, and experiments to show this became popular, and helped to interest the public in the new science; but the discovery of *conduction* and *insulation* was an enormous advance, and marks the year 1729 as an epoch. For from this time electricity could be caused to act at a distance, could be brought into a substance, and for a while retained there.

It is interesting to note also that in 1705 Gray called attention in one of the Royal Society's publications to the likeness between electric discharges and thunder-storms — a similarity also noted three years later by a Dr. Wall in the case of rubbed amber, with its spark and crackling sound. Still another important observation of Gray's is to be told, namely, that a solid and a hollow body of the same size, shape, and material, act alike when electrified. He reasoned from this that the electricity was at the surface, not

throughout the mass, a conclusion now accepted as true, and proved by many other experiments than the one performed by him.

The electrifying of the human body seems to have been successfully performed first by Dr. Dufay, of the French Academy of Sciences, and Gray repeated and amplified the experiment, for he was a most eager and skillful inquirer into nature. And Gray in turn was followed by Desaguliers, a French Huguenot brought to England in infancy, who repeated his experiments, and who made the observation that bodies that became electrified when they were rubbed were not good conductors, and *vice versa.*

When conductors and non-conductors were thus separated into classes, it was discovered, by Dufay, first, that all bodies could be more or less electrified, provided they were insulated; second, that water being a conductor, it was necessary to see that insulating substances were dry, and that conductors often acted better when wet; third — and most important — that there apparently were two different kinds of electricity, or at least that there were two states of electricity. One seemed to be caused by the rubbing of glass, the other by rubbing resinous substances. He called them, therefore, *vitreous* and *resinous.* Vitreous electricity attracted resinous electricity, and resinous, vitreous — each repelling its like.

Among substances regarded as giving rise to vitreous electricity may be named glass, crystal, precious stones, animal hair and wool; while resinous electricity was believed to be excited by rubbing amber, copal, gum-lac, silk, paper, and thread. For a long time what we now speak of as *positive* and *negative* electrifying were

known by the names *vitreous* and *resinous*. But now we know that the question of whether resinous or vitreous electricity results from friction, depends on the nature of both substances — so that the same body, rubbed by different substances, will produce different charges, either vitreous or resinous.

On the continent, the news of the discoveries of the French and English caused activity among the German and Dutch philosophers. Boze, a professor in Wittenberg added to the electric machine, in 1741, what is known as the "prime conductor"; that is, he combined the ideas of Newton or Hawksbee with those of Gray, and attached a "collector" of electricity to the glass frictional electric machine, insulating it, so that the electricity might be longer retained. Gordon, in 1742, used a long glass cylinder, instead of Newton's globe, and caused it to be rubbed by a fixed cushion, instead of by the hand. In this way, the machine became really effective, was rapidly improved in its mechanical construction, and operators could draw from it long sparks, of force and intensity enough to set fire to alcohol and even to less inflammable substances. With the ability to bring about strong electric action, many new and striking experiments could be tried, and more knowledge obtained of the laws of electric action and its conditions.

But a greater step was soon to follow. The prime conductor served to receive the electricity from the rubbed cylinder, but did not afford means for storing it up, since the insulation was imperfect. Consequently, men sought a way of collecting electricity *inside* of some insulating vessel. The simplest idea was to put it inside of a glass bottle. As early as

1745, a Bishop of Pomerania, named Von Kleist, put mercury into a bottle, and led a wire down into it. Then by means of a rude form of electrical machine he conducted the electricity along the wire and into the water. The experiment succeeded, and in removing the bottle he received a shock that seemed to him very strong.

During the next year, the same experiment was also made with *water* in the bottle, probably independently, by a Professor Muschenbroeck of Leyden, or by a pupil of his named Cuneus. Muschenbroeck says of the shock received, "I felt myself struck in my arms, shoulder, and breast. I lost my breath, and it was two days before I recovered from the effects of the blow and the terror."

The unexampled force of this new form of electric action caused great interest and excitement in all parts of Europe. The bottle, known as the Leyden jar, was eagerly studied by a number of philosophers, despite Muschenbroeck's alarming declaration, "I would not take a second shock for the kingdom of France." For the first time it was made possible to collect and hold electricity in a receptacle that could be carried from place to place, and to release the condensed charge by touching a conductor to the receptacle.

THE LEYDEN JAR AND DISCHARGER.

Houston, in his exhaustive work on "Electricity in Everyday Life," truly a small encyclopedia of the whole subject, has by quotation from an old treatise given a good idea of the interest excited by the invention of the Leyden jar. "Then, and not till then," says the old author, Cavallo, "the study of electricity became general, surprised every beholder, and invited to the houses of electricians a greater number of spectators than were before assembled together to observe any philosophical experiments whatsoever."

The Abbé Nollet, a French experimenter and a friend of Dufay, exhibited the power of the Leyden jar by causing three hundred soldiers to hold hands forming a chain, and then in the presence of Louis XV sending the electricity through them all. Other Frenchmen sent the current through a circuit about two miles and a half in length; and once the basin of the fountain at the Tuileries, containing an acre of water surface, formed part of the circuit. The English Royal Society outdid even this feat under the direction of Sir William Watson, noting so far as possible the laws of the action of the jar, and ascertaining that the electricity was felt instantaneously through 12,276 feet, over two miles of wire.

It was learned by these experiments that to get good effects there must be a conducting substance on the outside as well as on the inside of the jar; and Watson used tin foil on both outer and inner surfaces, finding it more convenient and effective than water. The electricity received from the machine was *positive* (or vitreous to use the old name); and just as when we magnetize a bar one end tends northward and the other southward, and two north poles repel each other,

but north and south are attracted, so in the Leyden jar it was found that to charge either surface positively, made the other surface negatively charged.

At first jars were made of larger size to get stronger effects, and then it was found that a number of small jars could be connected together by conductors — inner surface being connected to inner, and outer to outer throughout the series — and thus the effects of a single large jar could be brought about by a "battery" of smaller jars.

The means of condensing electricity into receptacles being found, there followed within very few years a large number of discoveries as to its properties. But in order that we may follow the progress of the science it is necessary that we should get a better idea of the nature of the subject these men were studying, some idea of its properties and laws.

CHAPTER V

FRANKLIN AND CONTEMPORARIES

We know all things by means of our senses. The effects on sight, hearing, feeling, taste, and smell are the only means by which we know of the outer world. About these effects and their causes we can reason in our minds, making guesses at how things will act, and why they act as they do. We can correct the report of one sense by another — as when we *see* that a person is in one place though some echo, perhaps, makes the ear report his voice as coming from another place. We can make guesses about causes, and then test our guesses by experiments, and in this way separate true causes from apparent ones. We can compare things unknown with things known, see likenesses and differences, and thus form an idea of what is likely to be true even of the unknown.

As to electricity, we can know only its effects upon the senses, or its effects in changing other effects on the senses. Thus it is that motion, heat, light, sound, weight, odour, taste are found by us in substances; and for ages these were all men knew of matter. Then began the collecting of facts due to something that seemed to cause some of these effects. A bit of rubbed amber caused motion. Light straws were seen to change place. Again the rubbing of similar substances in a more effective way showed the production of heat, and light, and sound, all produced by the condition caused by the friction of certain substances.

A name was given to this condition. The substance was called *electrified*, and that by which it caused effects was called *electricity*. Then it was said that electricity drew things to one another; repelled things from one another; warmed them, even burned them; would act better through some substances, and not so well through others; could be held in the condenser or Leyden jar, and then be let free at will. Next it was found that there were either two kinds or two states of electricity, and that these sought each its opposite, and .when combined seemed quiescent, when separated by non-conductors were as if confined and seeking release and reunion, which came about by action from the positive to the negative — from the vitreous to the resinous.

All these laws being known, more or less certainly, men began to guess about what electricity could be.

Thales named it a "soul" or spirit, which was little more than an empty word. Boyle spoke of an "effluvium," or outflow, which suggested a way of action. Dufay, and an Englishman named Symmer, called electricity "fluid," and believed all substances to contain two kinds, weightless, that united had no action, but separated by rubbing, gave rise to the observed action. And this was the state of men's guessing to about the middle of the eighteenth century, though Sir William Watson had added the suggestion that rather than two fluids, electricity might be one fluid in two states — the positive and negative.

Such, put in brief general form, was the state of electric science when Benjamin Franklin began his experiments and researches and his attempts to form a clearer idea of electric action. Franklin was always

interested in all subjects of learning, and besides being printer, author, and owner of a newspaper, had been member of the assembly and postmaster of Philadelphia. He organized the city's first police and its first fire-company, a militia, a hospital; he gave his attention to the paving of the streets, founded the University of Pennsylvania, the American Philosophical Society and the great Library Company of Philadelphia.

He became interested in electricity, and when the question whether thunder and lightning were caused by electricity in the sky occurred to his mind, his ingenious mind taught him a way to find out the truth. He had already drawn up a paper showing that the effects of electricity were the same as those caused by lightning.

It was in 1749 that Franklin noted the likenesses between lightning and electricity. He found they agreed in giving light and in its colour, in zigzag motion and swiftness, in being attracted by metals and conducted by them; in passing through water or ice, rending bodies they pass through, killing animals, melting metals, firing inflammable substances, and having a sulphur smell. These resemblances, added to the noise made by an electric discharge, caused Franklin to believe the two might be proved to be the same.

He hoped that a spire would be built in Philadelphia so that he might in some way attract the electricity from thunder-clouds. But, since no spire was built he became impatient, and decided to use a kite for the purpose of carrying a string into the stormy sky.

It had already been found that pointed conductors

best attracted electricity, and received it with the least disturbance. It is said that a friend of Franklin's, Thomas Hopkinson, discovered the power of points to receive or to set free electricity; and this is referred to in a letter of Franklin's dated July 11, 1747, and experiments proving it are described. So he placed a pointed wire about a foot long at the top of a kite made of a large silk handkerchief stretched on cedar sticks. To the kite was attached ordinary twine, but after the kite was raised, a piece of silk ribbon was led from the twine, and a key tied to the same place.

Of course the idea of Franklin was that if electricity was in the clouds, some of it would be attracted by the steel wire, would act along the conducting twine and key, and would be insulated by the silk — a non-conductor so long as it was dry. With his son Franklin stood under a shed to keep the silk ribbon dry, and awaited results. This was in June, 1752.

After some waiting the fibers of the twine were seen to stand apart — repelling each other, because electrified the same way. Then approaching a knuckle to the key, he received an electric spark such as came from electrified bodies. A Leyden jar was brought, and on being applied to the key collected electricity with which the usual experiments could be performed.

For the first time the lightning of the thunder-cloud, and the electricity known on earth were proved to be of the same essence. Franklin — the printer-boy — had dared to steal a part of Jupiter's thunderbolt, in order to prove that even the lightning obeyed laws that the brain of man might understand, and had bounds beyond which it could not stray.

It is not to be wondered that in his old age the American philosopher was glorified by the praise — *Eripuit cœlo fulmen, sceptrumque tyrannis.* "He snatched the thunderbolt from the skies, the scepter from tyrants" — a line written by the French statesman, Turgot, and imitated from the Latin author Manilius. It was praise well-earned by the superb courage that defied the lightning in the hope of gaining knowledge for the good of mankind.

As it was already known that the lightning was ended when it had reached earth, Franklin's inventive mind at once saw the possibility of placing a conductor upon houses, that would give the lightning a safer path to earth, and thus he invented the lightning-rod — a pointed conductor ending in the earth. And this was not only a path for the lightning stroke, but also a means of withdrawing smaller charges of electricity, that lightning might less often break forth.

After Franklin's researches had made experimenters familiar with the power of points to charge or discharge bodies, with which they are connected, they were often put to this use in apparatus — especially on the receivers of frictional electric machines.

From the Leyden jar, now that its charge was identified with the electricity of the clouds, there was much to be learned, of both lightning and electricity. Franklin studied the subject fully, declaring that the rubbing of glass did not create but collected the "electric fire," and then gave it out to any body possessing less. The inner coating of the Leyden jar received an unusual amount of the electricity, while the outer coating lost a similar amount. This was his idea of one being charged positively, or in excess,

having a *plus*, the other having a *minus* or negative charge.

Whatever his use of terms, he at least saw the truth that the two coatings were in a different state electrically, and that when a conductor was made to join them there was violent passing of electricity between the positive and the negative, and then they were in a like state, neither giving forth electricity. Therefore he was inclined to what was known as the "single-fluid" theory of electricity which ascribed electric action to the difference of the amount of so-called electric fluid in two bodies. Rubbing two bodies together causes electricity, it was believed, to pass from one to the other, whereby one becomes overcharged, the other undercharged, or one positive, the other negative.

Franklin also thought that the "electric fluid" repelled itself, so that two positively electrified bodies showed repulsion. Why two bodies negatively charged should show repulsion is, on his theory, not so easily understood. But though these early theories were great helps in finding the truth or the truer theories of later times, they are now replaced, and we need not therefore bear them in mind except as helping us to know the meanings of terms that came into use while those theories were held.

Nor must we think the old theories indicated ignorance in the authors of them. They were often the result of much deep thinking and experiment, and are usually nearer right than wrong. Though to-day we do not think of electricity as a "fluid," yet we still find the easiest way to explain many kinds of electric action is likening it to the flowing of water in pipes and from reservoirs.

While Franklin's kite experiment is perhaps the best known, there were at a little later time in Europe a number of electricians trying similar experiments by using long iron rods to attract the lightning. Among them may be named D'Alibard, who owed the suggestion to Franklin, but who drew sparks from the clouds some weeks before the flying of the Franklin kite.

But there were many sceptics who chose to doubt the experiment, as related by the American, so long as this was set forth only upon his authority. The Royal Society of London was one of the doubters, but soon admitted the importance of the occurrence. Franklin's account was translated into foreign languages, and in various ways and various cities philosophers sought to draw lightning from the skies. Among these disciples of the American were the great Buffon, the French naturalist; Beccaria, the Italian; Romas, another Frenchman, and a Russian, Professor Richmann. Romas used a kite, but added a wire to the cord, and succeeded in attracting a strong charge; while Richmann, having a metal conductor arranged from the roof of his laboratory and ending in a rod through the ceiling was instantly killed by a flash of lightning that struck the iron rod, entered his body at the forehead, and apparently left through the left foot, bursting the shoe.

Considering the daring of experimenters and their ignorance it is remarkable that the death of Professor Richmann is the only tragedy recorded in these early days of the science. Many others had set up pointed rods, and had discovered that there was often electricity in the atmosphere even when no thunder-clouds could be seen, or when the sky was cloudless. This

electricity is usually positive, especially in clear weather; in rainy weather it is generally negative, but may change often and suddenly.

Among noted students of electricity at this time was John Canton, an Englishman born in 1718, and thus about thirty-four years of age at the time of Franklin's kite-flying. He had already been interested in the Leyden jar, and had made many experiments in electricity and magnetism, being elected to the Royal Society and awarded a gold medal for a paper on making artificial magnets. He repeated Franklin's proof of the identity of lightning and electricity, being the first in England to do so, and read a paper describing his observations in which he mentioned the discovery that some clouds were negative and some positive. He was in correspondence with Franklin and became his friend.

He remained as he had begun, a schoolmaster, but to him we owe a number of discoveries in electric science. He found out that resinous or vitreous electricity might be excited in the same substance when rubbed by differing substances, and that the smoothness or roughness of the surface at times determined the kind of electricity produced. A glass tube, half rough and half smooth, was made by the use of a single rubber to produce both kinds of electricity at once. He invented putting an amalgam of quicksilver on the rubber of the electrical machine, thus increasing its action. But, a most important step forward, he discovered that electricity could be developed in a substance by the mere approach, *without contact* of an electrified body. This was the first discovery of electric *induction*, and was made in 1753.

This helped to explain the attraction and repulsion of light bodies by electrified substances. Suppose a cork-ball hung by a thread to be brought near a positively electrified rod of metal. At once, by this induction, the cork is electrified negatively on the side nearest the rod. It is then drawn to the rod, touches, is electrified positively by the stronger charge, and is then repelled since positive repels positive. It remains repelled until discharged by being touched. Then it is again attracted as before.

Canton in this way made what is known as the *electric chime*, placing little bells so they would when

Canton's Electric Chime.

positively electrified attract light balls that rung them, were then repelled, struck another bell that discharged their electricity, were again attracted, and so

on in a chime. He used this chime in an apparatus for collecting electricity from the air, and it began to ring when the apparatus was electrified by the air. By means of his experiments Canton learned that the air in a room could be electrified either positively or negatively, and so remain for some time.

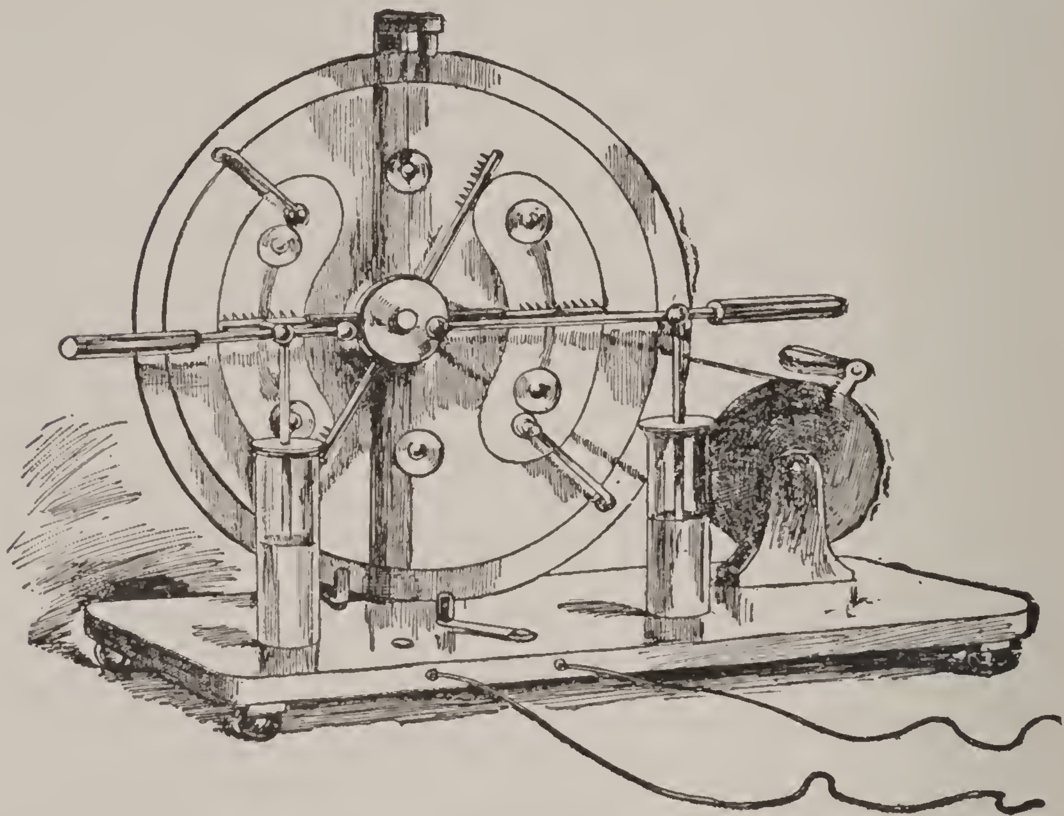
Beccaria, the Italian, made at this time a number of observations showing that water conducts electricity imperfectly except in large quantities, and that air near a body that had been electrified gradually acquired the same electricity, and parted with it but slowly, thus supporting Canton's induction discovery.

Robert Symmer, having noticed sparks and crackling when he pulled off his stockings, began to experiment with them, and concluded that the colour and material of the stockings made much difference in the electrical action. He charged a Leyden jar from the electrified stockings, and was led to adopt the two-fluid theory of electricity by his experiments, believing that the actions noted were explained by supposing two fluids that existed together, and gave rise to electric disturbance when their equality or equilibrium was disturbed.

So many men were now at work making experiments that space cannot be given to them all, especially as later observers have found out simpler or more direct methods of proving the facts they brought out. Thus it was found that a number of minerals became electrified when heated; that some substances showed electrical changes when melted, and that the shock given by the torpedo fish was an electric shock, produced by a true electrical apparatus.

In 1760 there was a most important change made in

the frictional electric machine. Ramsden used a glass disk instead of the cylinder, — to the machine's manifest improvement. But more important than any



Frictional Electric Machine for Producing Static Electricity.

general observations, or even the improvements in machines were the accurate researches carried on by the deep scholar Henry Cavendish, who in 1771 published in the papers of the Royal Society of England, a theory of electricity. Cavendish measured the resistance of various substances to the passage of electricity, examined the capacity of glass plates to hold electricity, and studied the results of passing the electric spark through mixtures of gases. Others had taken apart water into oxygen and hydrogen by passing electricity through it; and Cavendish by experiment was able to make them again into water by exploding an electric-spark in the right mixture. But though these

were the beginnings of electro-chemistry, a science possibly destined to produce the greatest effects on human life in the future, the investigators did not carry them further, and it remained for future years to develop the hints they contained, just as coming men will develop ours.

CHAPTER VI

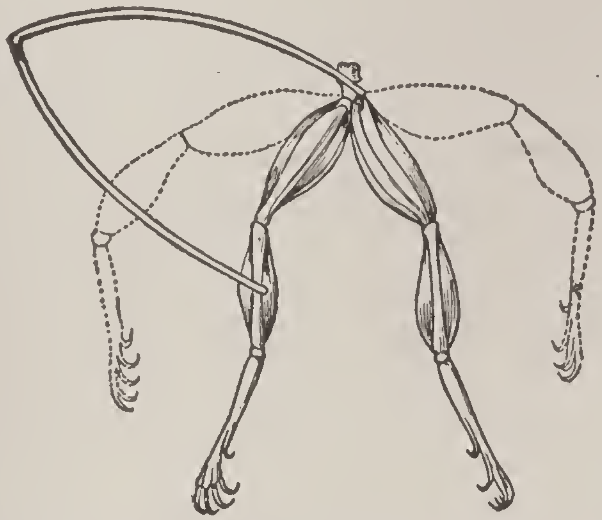
GALVANI, VOLTA, AND THE CELL

As electricity was more and more studied, inventors tried to devise ways by which it could be measured. Cavendish had examined into the resistance of conductors, and Coulomb, who lived about the same time, took up the question of quantity. He devised a way to measure the force of electric or magnetic action. For this purpose he made a glass jar in which from a fine wire hung a needle of shellac having a gilt ball at its end. By lowering a charged rod into the jar, the ball was repelled, and the wire twisted to an amount measured on a scale, thus showing the strength of the repulsion from the rod. A similar balance was used to test magnetic force.

From the experiments made Coulomb declared that the action of magnets was inversely proportional to the square of the distance; that is, at half a given distance the force was four times increased; at one-fourth the distance, sixteen times increased. This same law applies in the case of electricity, when the balls electrified are small. His balance also showed that electric charges repelled or attracted with a force equal to the *product* of the charges for a given distance.

Coulomb gave out a double-fluid theory of magnetism in 1780, which was little more than an adapting of the electric theory to the actions of the magnet. We need not discuss it, since the fact that one magnet will magnetize many others without losing power seems a

fair proof that magnetism is not to be considered a fluid; besides, modern theories seem more probable. But Coulomb's measurements enabled him to find out just how magnetism was distributed in magnets, and that electricity distributed itself equally between spheres of the same size, but differed in density at various points, and on bodies of various shapes, and so on. In short, he collected a great number of careful observations and attempted to explain them by a theory that helped greatly in the exactness of the science, and practically showed how to make conductors, condensers, and insulators more effective and perfect — all of which was most valuable to later ex-



GALVANI'S EXPERIMENT WITH THE FROG'S LEGS.

perimenters, and secured for Coulomb the fame of having the electrical unit of quantity (that unit by which amounts of electricity are measured) called in recent years by his name — *the coulomb.*

The last few years of the eighteenth century saw also the rise of what was almost a new science of electricity, through the discoveries of the Italian Galvani, a professor in the University of Bologna. One even-

ing in his laboratory while investigating the effect of electricity on animal organisms, he used frogs' legs as a means of detecting delicate electric charges. Then having bound them together with copper wire they were hung against an iron railing in a window, and immediately became "powerfully convulsed." Such is one story of the happening. Another is quite different, and says that frogs' legs broth had been ordered for Madame Galvani because of her having a cold. The skinned legs were lying on a table near an electric machine in action. An assistant touched them with a metal instrument, and they were violently affected. Madame Galvani noticed the occurrence, and her husband investigated it. The first story is favoured by Dr. E. J. Houston for the reason that a document exists showing Galvani had used frogs to test for electricity several years before the date given to that story, whereas the frogs' legs-broth incident is dated later than the first. Probably the discovery was earlier than 1786.

Though a Dutch physician, Swammerdam, had more than a hundred years earlier shown that frogs' legs would twitch when touched by metal wires, Galvani undoubtedly knew nothing of this when he announced his discovery of "animal electricity." He thought electricity might be secreted by the brains, and then stored in the muscles, as if in Leyden jars, from which the nerves conducted it. So he formed a branched fork of metal wires, copper and silver, and caused convulsions of the muscles by touching one end to them, and the other to a nerve. These experiments were repeated in various ways and an account of them published.

Galvani himself lost his professorship because he

would not swear allegiance to the Cisalpine Republic, and though restored, could not return, but died in retirement. His name remains enshrined in the term *galvanism*, and its derivatives.

Though he did not greatly profit from his own experiments, he furnished to another the means for a great discovery and invention — no less than a new source of electricity, and a source far superior to the old electrical machines. This other was Alessandro Volta, also an Italian, and a native of Como, the birthplace of the two Plinys. Volta was a professor of physics, but had travelled widely and formed friendships with many distinguished men of science. He had written on the theory of electricity, adopting with some change the single-fluid theory of Franklin, and suggesting that electricity might be produced in other ways than by friction, such as in chemical action, by evaporation, melting, burning, and mixing. About 1774, or a little earlier, he betook himself to experiments, and in the next year described an invention called the "Electrophorus" or electricity-bearer.

This is a resinous cake, which has been melted and permitted to set or harden in a metallic dish. On this rests a metallic disk, with an insulated handle, of glass for instance. The resinous cake is excited negatively by friction with cat-skin, and then the metal disk is placed upon it, touched with the finger, and lifted, whereupon it will be found heavily charged with positive electricity, and will give off sparks. But meanwhile the resinous cake retains its charge, and will induce a second charge in the metallic plate. Rubbing electrifies the resin negatively. The disk being applied, its positive electricity is attracted to

the lower surface, its negative repelled to the upper. The finger touch conveys away this negative electricity, and the disk retains only the positive.

This can be repeated again and again. The electricity in the electrophorus is believed to come from the force exerted in pulling or lifting the disk with its positive charge from the resin with its negative charge.

But each time the finger must touch it before it is lifted, for this carries off the negative charge,

THE "ELECTROPHORUS."

leaving the positive to be retained by the induction of the negative cake. Perhaps this will be best understood by imagining the two kinds of electricity on each side of the metallic plate, and the negative to be allowed to escape from the upper side through the finger and body to the ground.

This was a most convenient little apparatus, giving a

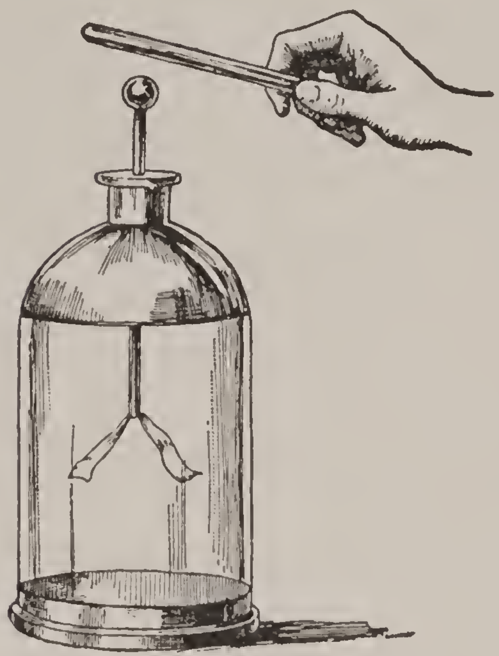
strong charge that could be again and again repeated without again rubbing the resinous cake until its influence had slowly passed away. Volta spent some time in improving this apparatus, and likewise gave his attention to various ways of storing electricity in condensers, and to an electric balance for the measurement of electricity. He separated electrified plates, one of which was hung at the end of a beam, by weights put into a pan at the other — which is declared by the "Encyclopedia Britannica" to be the first electrometer. For in this balance electric resistance was measured against *weight*, and the same measurement could be made by others with other balances. Other of his studies related to the discharge of electricity through points and flames.

Volta was much interested by the experiments of Galvani and repeated them; but soon he came to disagree with Galvani's explanation. He believed the electricity to be derived, not from the animal tissues or nerves, but from the metals used in the experiment, and to come from their contact alone. To prove this, he devised very delicate tests. His instrument was called a condensing electroscope.

An ordinary electroscope (or electricity viewer, as the Greek words may be translated) consisted of two pith-balls or strips of gold leaf, hung from a conducting wire and put into a glass jar so that the air currents may be kept away. An electric current or charge makes these both negative or positive, and they stand apart repelling one another.

Volta added to the top of the wire a flat plate of metal, covered with a waxed silk cover and applied a second plate to the cover, the second having an in-

sulating handle. When this second plate was electrified even in very slight degree, it accumulated the charge precisely as a Leyden jar would, for the finger was placed on the lower plate to discharge the negative electricity. Then the top plate was lifted leaving the lower plate's electricity free, and at once the leaves or balls of the electroscope were repelled.



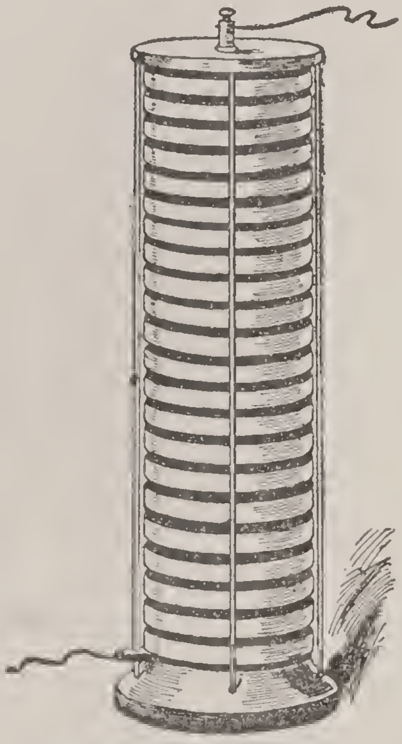
THE GOLD-LEAF ELECTROSCOPE.

This instrument was one hundred and twenty times more sensitive than the simple electroscope. It is, as the reader will see, a combination of the Leyden jar or condenser principle with the principle that like electricities repel one another.

Using this sensitive test, Volta put together various metals, and held them against his condenser electroscope. He detected electricity in the combined metals, but also found out that the frogs' legs were, as an electroscope, much more delicate than his condenser electroscope, being affected when that instrument would not indicate any electric action whatever.

Having perfected his tests, Volta was able to compare results, and found the best results came when different metals were in contact, especially if used with salty or acid solutions. He used these solutions because it had been shown that they helped to get good results with conductors, insuring closer contact. But from the use of the acid solutions with metals

they would act upon chemically came a most important discovery and invention. This is the well-kown Voltaic Battery or Pile — a device that was to cause enormous advances in electric science and the arts coming from it. As Volta described it in a letter read before the Royal Society in June, 1800, it consisted of "several dozen disks of copper, brass or silver, and an equal number of disks of tin or zinc, of the same size." Zinc and copper alternately are usually chosen. Between each pair, is a cloth disk dampened with salty water, slightly smaller, forming a pile or column. First copper, then zinc, then cloth, and so on, being careful to complete the pile with the metal disk different from that which began it.



VOLTA'S BATTERY OR PILE:

Consisting alternately of disks of copper, zinc, and cloth repeated.

This pile was then enclosed in a little frame of glass pillars, a wire attached to the top and another to the bottom disk, and electricity was *continuously* produced as soon as a conductor joined the two wires. It was the first means of producing a continued flow of electricity. The force of this current was less, but its quantity was enormously greater than that of the electric machines working by friction or induction. To compare the flow with the flow of water, it is like water flowing slowly in a big pipe compared to water flowing quickly in a small pipe. The latter is more forceful though less in quantity. The voltaic pile

gave more electricity in a less forceful way; and, besides, it proved that what was known as galvanism was only electricity produced by different means. Volta made a number of improvements in his apparatus, and was engaged in the controversy that took place between those who thought the electricity came from the mere contact of the dissimilar metals, and those who believed it came from the chemical action of the solution — as is now generally accepted. The discussion of this question was said to have caused enough ink to flow "to float the Navy of Great Britain" — though one would think less use of ink and more use of the chemical solutions would soonest have settled the great dispute.

The voltaic pile was capable of improvement as soon as it was understood. It was troublesome to dampen the disks of cloth, and they soon dried. Consequently ingenious workers, including Volta himself, used the same principle to build better apparatus. He made a number of separate piles, connecting top disks and bottom disks by conductors; this prevented the weight of the disks from squeezing the cloth dry so quickly, or from making the moisture run down the sides. Then he devised another apparatus, consisting of cups to hold the acid-water solution while the pairs of metal plates were set into them. Each copper plate was soldered to the zinc plate in the next cup, the conducting wires being soldered to the first copper and the last zinc. This made a true electric battery. He called it a "crown of cups," since he placed them in a ring so as to bring the two ends of the series near one another.

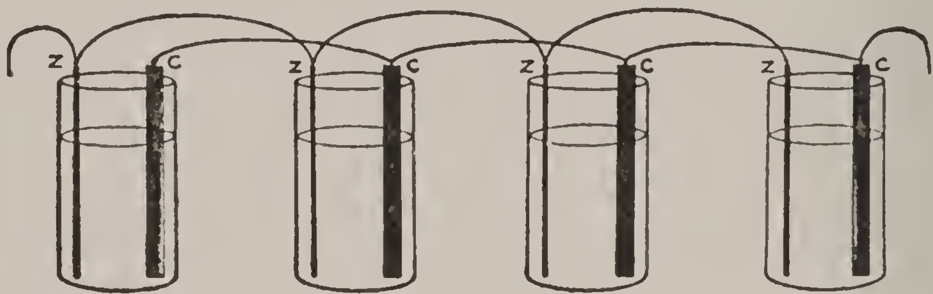
But in order to prevent the action of the battery

when not in use, it was not convenient to lift the metal pairs separately out of the solutions, and so means were adopted for fastening them to a single support, such as a bar of wood. This was invented by Dr. Wollaston, who also devised a way of bending the copper plates in U-form, hanging each zinc plate into the space between. This made a larger surface over which there was action, and thus the cells were more effective. Others brought about the same improvement by coiling the plates into cylinder form, thus making room for more surface in the same size cell.

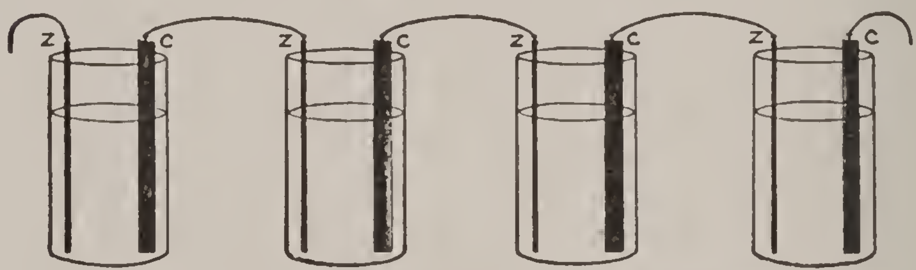
Another method of changing the action of the cells is by connecting them differently. It will be seen that all the zincs, and all the coppers must be connected, but this can be done in two ways: We may connect all the zincs together, then all the coppers together, and afterward may connect the united zincs to the united coppers; or, secondly, we may connect a zinc and copper, then another zinc and copper, and so on, and then connect these couples. Here are the two ways: Z+Z+Z+Z+C+C+C+C and Z+C+Z+C+Z+C+Z+C. Now, if a wire were to be run, in each group, from the first Z to the last C, we should have the two kinds of cell connection. The first sort is known as multiple-connection, the second as series-connection.

The effects of the two connections vary. If we compare the flow of electricity to the flow of water, we shall see that series-connection is like running water through a long narrow channel, while multiple-connection is like running it through a broader and shorter channel, or through a number of parallel channels. In the first case the water meets more

friction, or resistance, but will (for a given pressure of water) flow with more velocity. In the second case, the water meets less friction, and flows with less velocity. But the series-connection gives a stronger current in less amount; the multiple gives a weaker current in larger amount.



VOLTAIC CELLS ARRANGED IN MULTIPLE-CONNECTION.



VOLTAIC CELLS ARRANGED IN SERIES-CONNECTION.

Or we may say that connecting all the zincs together *adds* them — makes them equal to one big zinc plate the sum of them all; and connecting all the copper plates has a similar effect. Thus, small cells connected in multiple become like one large cell.

Of course, as with the water, we cannot have both more *and* stronger electricity-action, any more than we can with the same mill-stream run a bigger mill faster with the same amount of water-current. We can let the water run a row of little wheels, or turn one big wheel more slowly, as we may choose.

It is important to understand this because the rule applies all through the whole science and art of

electricity — the idea being the same as is expressed in the old proverb — "You cannot eat your cake, and have it too." However we may connect our wires, we shall be forced to choose between more or less, stronger or weaker — as in mechanics we must sacrifice power to get speed, or speed to get power. And electricity, after all, is only another example of mechanics, action taking place subject to the same laws.

There are still other ways of connecting the cells, by combining these two main systems. Thus we may connect two *sets* of cells in series, and then connect the sets in multiple; or we may connect sets in multiple, and then connect these multiple-sets in series. To diagram these we may use letters as before: $\begin{array}{c}Z+C+Z+C\\Z+C+Z+C\end{array}$ represents two series-connections, and these may each be treated like a cell and joined *in multiple.* While $\begin{array}{c}Z+Z+Z+Z\\C+C+C+C\end{array}$, representing multiple-connection, may be joined *in series.* The question as to what kind of connection is made may be decided by following the imagined course of current. To proceed through both elements of a cell and then through both of another cell, is to proceed in series; to proceed through one element of all cells, and then through the other element of all, is to proceed in multiple.

Where the two ways are combined, consider each group separately, and remember that the amount and the pressure of electricity are governed by the original strength of the current caused by the action in the batteries as modified by the resistance of the work it has to do by passing along the conductors — in which must be included everything affected by the current, the plates, the solution, the connections, and the conducting wire.

It is impossible here to give even in briefest form all the different modifications of the voltaic cell. They are based upon the same general principles, and can be understood if these are borne in mind. As better means of bringing about the effects were invented, we shall speak briefly of their principles, and of their inventors.

CHAPTER VII

THE PIONEERS OF THE SCIENCE

By means of the voltaic cell it became possible to make electrical experiments on a large scale. Though the early batteries, like all early forms of apparatus, were in certain ways crude, and though such batteries soon ran down in strength, yet they could for a short time be made to yield large amounts of electricity, or electricity in continued currents. Thus we reach an era in the science — the era when current electricity could be used in experimental work.

One of the very earliest to profit by the new source of electricity was Sir Humphrey Davy. Born in Cornwall, England, two years after the Declaration of Independence, son of a wood-carver, he is said to have been noted in his youth for nothing except his "retentive memory, facility in versification, and skill in story-telling." So the Britannica declares, apparently without suspecting that these are the very qualities to make a great investigator — remembering, constructing, and imagining. Davy became apprenticed to an apothecary and doctor, and was studious in educating himself. When nineteen he was interested in chemistry, and scared his household by garret explosions.

He was lucky enough to be noticed by appreciative men, and was engaged to take charge of a pneumatic medical institution — whatever that may be! At all events, it was an employment that helped him to study

chemistry and physics. He found out that the mineral silica was in the stems of reeds, corn and grasses; discovered in 1799 that nitrous oxide gas ("laughing gas") would intoxicate; and tried to find out what "heat" was, by causing pieces of ice rubbed together in a vacuum to produce heat.

His first book of "Researches" caused him to be recommended as a lecturer on chemistry to the "Royal Institution," recently established in London. He became professor of chemistry in 1802, attracting great audiences by his brilliant lectures and ingenious experiments. Though ungainly and awkward in movement he was "animated, clear and impressive" in speech, and soon became very popular in the city, and also with the management of the Royal Institution.

The members of this body put under Davy's control enormous voltaic batteries, with which he could make most helpful experiments.

First of the discoveries he announced was the making of a voltaic battery with *one* plate of metal, and *two* fluids. There followed a long list of brilliant papers, hardly one of which failed to "announce some new and important fact, or elucidate some principle." But especially he explained that both "electrical and chemical attractions are produced by the same cause, acting in one case on the particles in the other on the masses." Decomposing certain alkalis by the electric current he discovered in 1807 sodium and potassium and three other new metals; and later he carried on extensive chemical researches in electro-chemistry, showing that chemists were to find in the electric current a marvellous new assistant. This use of the electric current had been made in the year 1800 by

Nicholson and Carlisle, two English experimenters, who decomposed water into oxygen and hydrogen; but Davy had been able to systematize the work and discover its laws, and thus to make the beginning of a new science and art.

Likewise in 1802, Davy, by sending the electric current through a circuit ending in two pieces of willow charcoal — carbons — had shown that a brilliant arc of light was produced; but it was reserved for his helper and follower Faraday, to discover the cause and the laws of this brilliant light, and thus to make it useful.

About 1808, the batteries with which Davy had done so much were worn out, and in July a few members of the Royal Institution took up a subscription that furnished him with an enormously powerful new battery of 2,000 plates. With this battery he obtained intense currents, and showed the arch of light — the "carbon voltaic arc" — in great brilliancy and beauty. He also noted the intense heat of this electric flame, finding that few substances could resist it. But striking as were these experiments, they were for the most part only doing on a different scale what had already been done by the use of smaller batteries, or by means of electric-machine currents.

But Davy's experiments and researches bore more especially upon the chemical side of science, and, to the end of his life, in 1829, he never ceased to make useful discoveries and inventions, and to write on scientific or literary subjects. One of his last pieces of work was a study of the "Electricity of the Torpedo" (meaning the fish, of course).

Davy's greatest services were to electro-chemistry, but he also did much to prepare the way for his suc-

cessor at the Royal Institution, Michael Faraday, by attracting the attention of the public and by creating interest in scientific work.

Meanwhile, there were workers in other branches of electric science who were likewise preparing the road for their successors. In 1803, it is said that a French experimenter, M. Carpue, published certain investigations on the curative effects of the electric current; but the applications of electricity to medicine had no wide development until some years afterward, when the discoveries of Faraday had given the science a practical apparatus.

About 1805 an Italian pupil of Volta named Brugnatelli, carried further some experiments made a few years earlier, and succeeded in causing the electric current to deposit a plating of gold upon two silver medals. It was not the first time this action of the current had been observed, but seems to be the first practical use of the power of electro-plating, and therefore the true beginning of a process that has been developed since in so many useful applications.

Indeed, after a certain process has been developed, we may almost always find that, in some cruder form, it has existed for a number of years with its possibilities unrecognized. And this is peculiarly true of electricity. As we read the records, we shall find in these early years of the nineteenth century, and before, the germs of the whole science of electricity. One or another experimenter in his laboratory reaches a result that, if it had been keenly followed up, might have led to results that in fact were not reached for many years thereafter.

Davy's production of the electric-arc is an excellent

Portrait of President Roosevelt Telegraphed by Korn System (*See also page* 303)

example. But even where the possibilities of a discovery are vaguely seen, the practical working out of its applications is a matter dependent upon many elements not yet in right condition. Davy, for instance, could not foresee how electric currents might become commercially cheapened in cost, so that the effects of his enormous battery might be secured from the power of a small waterfall or a steam engine.

The telegraph was also foreshadowed long before it became a practicality. Lesage, of Geneva is said to have practically applied the idea of using frictional electricity in sending messages as early as 1774; and, in 1802, the fact that a current would move a compass-needle was observed by Romagnosi, according to Elihu Thomson, but no application was made for many years. In 1809, a still further step toward telegraphing was taken by Sommering, a German, who is credited three years later with using a telegraph made of thirty-five separate wires each connected to a point projecting upward through the bottom of a glass reservoir containing acidulated water. When a current was sent through any wire, gas was seen to form in bubbles on one of the points in the water. An American, Dr. Coxe, of Philadelphia, described a similar telegraph about the same time.

But all these inventions were attempts to follow up paths that were not in the true line of progress, and are mentioned here only to show the reader how many developments of electric science are attempted, in seeking for the true path of improvement and success. We cannot mention even a tenth part of them, but must select only the more striking and more fruitful discoveries and inventions.

Passing over, therefore, the first attempts at a battery that would store up electric energy, the first use of the electric spark as a fuse to fire explosives, and the so-called "dry-pile" — a voltaic pile supposed to act by mere contact of metals, but really influenced by moisture taken up from the air, we shall next examine the experiments of Oersted, for these proved to mark an era in the science.

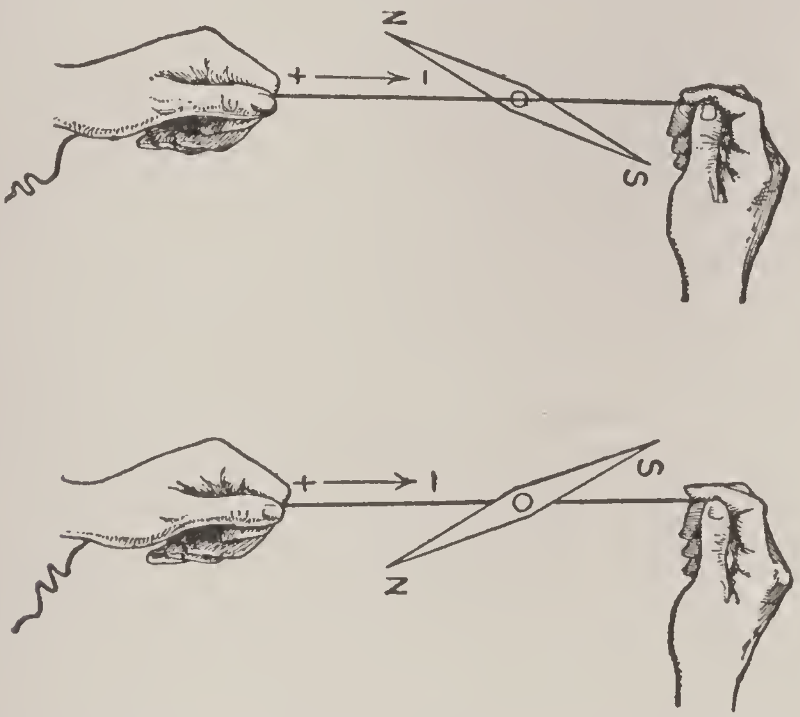
Hans Christian Oersted was a Dane, son of an apothecary, and was born in 1777. Like Davy, he began at an early age to experiment in chemistry and physics, and he was graduated at the University of Copenhagen. About 1800 he became interested in galvanism and electricity, and after several years' travel lectured on the subject, being appointed professor of natural philosophy.

He published papers showing the identity of chemical and electrical action, and upon various subjects tending to make science popular, and was much aided by the friendship of scientific men, and by membership in the learned societies of Europe and England. Oersted was honoured by a great national jubilee in 1850, and died in 1851.

His discoveries were numerous, including a proof of the existence of the metal aluminum, but in electric science he deserves especial fame as the one who proved the identity of electricity and magnetism. He produced magnetism by using the electric current. He was led to this discovery by having noticed that the passage of the electric current near a magnetized needle caused it to turn, and by experiment found that the needle placed itself at right angles to a plane through the current and the needle center — or

crosswise to the current. Oersted is believed to have supposed electricity might be a form of magnetism; but by the investigations of the French philosopher, Ampère, who analyzed and systematized Oersted's experiments, it was made probable that magnetism might rather be regarded as a form of electric action.

In 1820, the year following Oersted's discovery, Ampère was able to declare the existence of many



OERSTED'S DISCOVERY OF MAGNETIC DEFLECTION
Above the needle, the current turns the needle one way; below it the other way.

laws governing the action of electric currents and their action upon one another and upon magnets. He thus became the founder of the science of electro-dynamics, or electricity acting as a force, being the first to declare the laws that explained and the principles that governed the electric action of currents.

Ampère was a most precocious boy, born in Lyons in 1775. He said in later life that at eighteen he knew all the mathematics he ever learned; but besides his

skill in this one branch, he seemed to have a general thirst for knowledge, reading the whole encyclopedia through. Ampère's father was executed by the revolutionists in 1793, and the son was thereby so affected as to remain for over a year in almost a stupor. From this he was aroused by a treatise on botany that awakened his interest, and restored his love of knowledge. In 1801 he became a professor of physics, then of mathematics, and four years later became attached to the Polytechnic School in Paris.

Hearing, in September, 1820, of Oersted's discovery about the magnetic needle, within a week he presented a complete explanation, and new discoveries showing that the currents in wires attract or repel one another as magnets do, but tending to arrange themselves so that their currents will flow in the same direction. In 1821, he suggested an electric telegraph with a separate wire for each letter. He died in 1836.

His expression of the law governing the deflection of the needle is very simple. Supposing a person to be lying in the direction of any current, so it flows from feet to head, and to face the needle, Ampère stated that the north-pole of a magnetic needle always turns to the left until the needle lies across the current. The rule is stated in Guillemin's "Electricity," probably by the editor, Silvanus Thompson, as follows: "When the current flows from *South* to *North* *over* the needle, the needle's north pole turns *West*." And the reader is told that the initials of the four italicized words spell S-N-O-W, by which means the law is readily recalled. Of course, if the current flows *South* to *North under* the needle it turns to the *East*.

The importance of this discovery lies in the fact

that it offers a simple means for determining the existence and direction of the current in any conductor, and also brought electrified conductors and magnets under one classification. The Britannica declares, that except Faraday's later discovery of the laws of induction of electric currents, "no advance in the science of electricity can compare for completeness and brilliancy with the work of Ampère."

CHAPTER VIII

FIRST ELECTRIC MOTORS, AND THERMO-ELECTRICITY

Ampère tried the experiment of coiling a conducting wire into a spiral or helix, and found that when electrified such a coil had the properties of a magnet; and that a straight bar of soft iron is drawn into the middle of the coil, there becoming a magnet with a pole at each end, was the discovery of Arago, who carried Ampère's experiments further. Davy also made the same discovery independently in the same year, 1820.

The life of Arago, which he himself has written with French humour and vivacity, is most dramatic and exciting. Born in 1786, he longed to be a soldier, and studied hard to fit himself for the Polytechnic school. He read eagerly, bearing in mind D'Alembert's maxim, "Go on, and the light will come to you," and was admitted in 1803, meaning to fit himself for the artillery. But in 1804 he became secretary to the Observatory at Paris, and thus met many scientific men. He was engaged about 1806 in measuring the meridian that formed the basis of the metric system, and met with most exciting adventures among the Spanish mountaineers, for he was thought to be a spy. After an imprisonment he escaped, fled to Algiers, and then disguised sailed for Marseilles. Captured by corsairs, he was rescued from a second imprisonment

only after a long time, and even after this met with a whole Odyssey of adventures in his attempts to carry the record of his survey to Paris.

He was congratulated by the great Humboldt upon his safe return, and became a professor at the Polytechnic, a member of the French Institute, and one of the astronomers at the Royal Observatory. He was a lecturer noted for brilliancy, a writer of great clearness and force, and a patriot not without power to do service to his native land.

He visited England more than once, and made warm friends among the most prominent scientific men. His political life is quite as interesting and exciting as his scholastic, but cannot be here entered upon, even in the briefest summary.

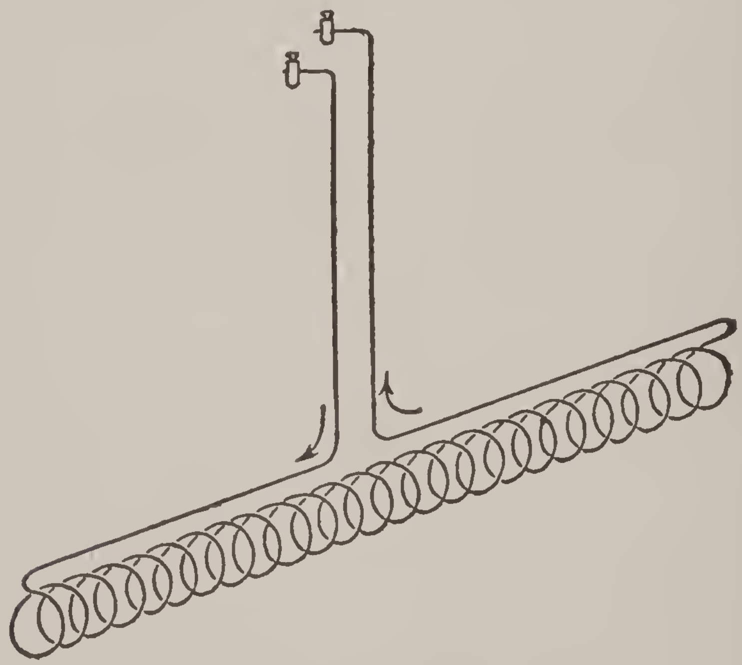
His researches in electricity and magnetism were most important. He made a study of the effect of various non-iron substances upon the magnetic needle, and found that when it was set swinging above various materials — as ice, glass, copper — the needle swung less long and less widely as it was brought nearer the surface. This effect is known as the "damping" of the needle.

Then he tried revolving the substances near the needle, and made a discovery that proved most important. Revolving a copper plate below the needle, he soon found that the needle began to spin. This was an astonishing and unexpected result, and was not fully explained until the investigations of Faraday in England some years later. Arago, as before noted, also was the first to magnetize steel by means of the electric current.

He discovered, first, that an electrified wire attracted

iron filings; then, that steel needles or bars, so attracted, retained magnetism; then, that these were best magnetized when the wire had been coiled spirally, and the bar put inside the coils. The coil, or helix, was first used by Ampère, and the properties of this helix or *solenoid*, as it is called, from a word meaning tube-like, were more exhaustively studied by Arago.

It is difficult to keep events in their right order during the busy years from 1820 to 1830, for it was a



AMPÈRE'S SOLENOID OR COIL.

time of many investigators working along similar lines, reporting the results achieved to one another, and repeating with changes the various experiments made. The general advance in the understanding of the laws of electric currents, of batteries, of conductors, and of magnets, had put into the hands of scientific observers the means of forming and testing theories, while the writings of Ampère, Arago, Davy, and their fellow workers put others upon the right

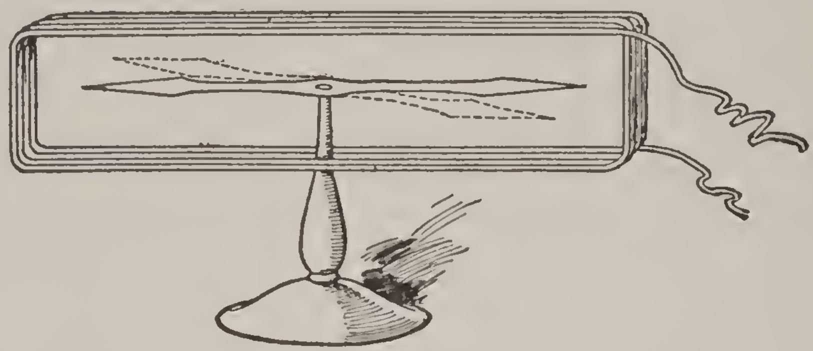
track, and saved them from repeating researches already made.

About 1821, Michael Faraday, who had been appointed Davy's assistant came into especial prominence by his discovery that the electrical current could be readily converted into a continuous mechanical motion. Faraday was born in 1791, the son of a blacksmith, and first worked as an apprentice to a bookbinder. He had a fondness for study, and was taken by one of his master's customers to hear four lectures by Davy at the Royal Institution.

The young man took notes and wrote out the substance of the lectures so successfully that he was encouraged to send them to Davy himself.

Davy replied kindly, and later recommended Faraday as assistant in the laboratory. This began a connection with the Royal Institution that continued for over half a century. Though Faraday's work was brilliant in many departments, and especially in chemistry, yet in electricity and magnetism he accomplished most, and to these subjects he devoted himself most completely. While in 1821 the great discovery of Oersted was interesting the scientific world Faraday happened to be present when Dr. Wollaston and Sir Humphrey Davy were discussing the possibility of making a conducting wire rotate by means of its own current. Oersted having shown that the current would move a magnetized needle, it was natural to consider the effect of fixing the needle while leaving the wire free to rotate. To the experiments of Oersted, Schweigger had added further facts by bending the wire around the needle, finding that every part of the electrified wire helped the motion of the needle; and

when the wire is bent into a hollow rectangle or a set of rings, the effect of the current is increased by every turn. In this way the current is multiplied, so to speak, and even a weak current produces a strong effect upon the needle. This device known as a "Multiplier" at once came into use in the form of a test



SCHWEIGGER'S MULTIPLIER.

and measure for currents, being called a galvanometer. Of course the resistance to the current increases with the length of coils of wire, so the turns must be proportioned to the strength and amount of the current to be measured.

It was in attempting to solve the problem of causing rotation in a conducting wire that Faraday made the first of all electric motors, the germ from which all later forms may be shown to be derived.

Dr. Wollaston's visit to Davy was in April, 1821, and in July, August and September of that year Faraday wrote for publication a sketch of electro-magnetism, repeating the experiments he described. This led him to the discovery of a means of making the electric current convert itself into mechanical motion. His method was to suspend in a glass cylinder corked at each end a wire hung from a hook, and dipping into mercury at the bottom of the cylinder. In the mercury *floated* a bar magnet, anchored so as to stand

upright. The current was passed through the wire down into the mercury, and then out through a wire extending down through the lower cork.

The current in passing caused the magnet to move or rotate around the wire. As will be seen this is to repeat Oersted's experiment with a *fixed* wire and *free* magnet. Another account says that in the early experiments the magnet was fixed in the cork, and that the wire revolved around the magnet; but in either case the principle is the same.

There is also a difference of opinion as to the time when Wollaston's visit was first made to the laboratory, but as Faraday himself acknowledges that Wollaston was the first to suggest the possibility of causing the rotation, the matter is not very important.

In order to understand the action of Faraday's apparatus it will be necessary to examine something of the theory by which it is explained. Up to the time of Oersted a magnet was thought to contain something they called the magnetic fluid or fluids. But when he had discovered that the electric current acted on the magnet, this belief was given up, and after Ampère had studied the matter a new theory was accepted. According to Ampère every magnetic substance was the seat of electric currents passing among its particles in all directions. When magnetized, these currents were brought into united action, and in the permanent magnet, the currents all went in parallel directions crosswise to the two poles.

Then, after it had been shown that currents acted on one another as magnets do, the magnet became only a collection of currents — as if made up of many coils of wire each containing a moving current of elec-

tricity. Next, experiment showed the laws of attraction and repulsion applying to moving currents, and they were found to be, in general, these, as Ampère stated them:

1. Conductors carrying currents, if they are parallel and the currents in the same direction, attract each other. If the currents are opposite, they repel.

2. Conductors both coming together at an angle or both diverging, attract when carrying currents going in the same direction toward or from the apex of the angle. If the conductors carry currents in opposite directions, they repel.

3. A sinuous (or wavy) conductor acts like a straight conductor under the same conditions.

From these laws it would seem to follow that currents at right angles to one another are equally repelled and attracted. But of course so exact a balance of forces would be as difficult to bring about as putting a bit of iron below a magnet so near that it would hang in air, balancing its weight against the magnet's upward attraction.

Now, if the reader will consider Faraday's experiment of a wire hanging into a cup of mercury, he will see that at any position of the wire the attraction of the magnet's currents will be exerted from one half, and their repulsion from the other half — as if the wire were a hanging magnet and another magnet were carried around in the direction of the current, when one pole of the horizontal magnet would be always repelling, and the other always attracting the pole of the magnet hung so as to bring one pole within the influence of the revolving magnet.

It is necessary to understand this action, since Fara-

day's crude little apparatus was most important, "embodying as it did," to quote Professor E. J. Houston, "practically the fundamental principles of the electric motor of to-day."

The interactions of the electric currents with one another and with the magnet were also observed in other forms. Thus, when a magnet was brought near to the electric arc between the carbons, it was found by Davy that the arch of light was drawn from its place between the carbons, being either attracted or repelled according to the laws announced by Ampère. And the rotating of a conductor was brought about, also by Davy, in a dish of mercury, the liquid answering to the laws just as the conducting wires, the magnets, the arc-light, and other electric manifestations had done.

About 1823 there was discovered another new method of causing the electric current. First, it had been excited by friction, leading up to the development of the powerful electric machines, which had led to the discovery of electricity by induction, and to the electrophorus, and the Leyden jar; then it had been produced by the voltaic pile, leading to the electric voltaic cell and batteries. And now an experimenter named Seebeck found a new way to obtain electric currents.

As in the case of frictional electricity there were certain ancient observations giving the hint of what lay concealed. Pliny told of a crystalline stone that when heated attracted light bodies, and there had been experiments made especially with the mineral tourmaline to investigate its property of attracting and repelling light substances when heated and cooled.

When this property was definitely connected with electric theories, the action was named pyro- or fire-electric. When the crystal was heated, poles were developed that acted like those of an electrified conductor.

But though many had experimented with various crystals showing such properties, there had been no striking developments. Professor Seebeck, of Berlin, discovered that instead of being confined to certain natural substances, the property of giving rise to an electric current when heat was applied or a change of temperature affected, was general among all metals, providing certain conditions are fulfilled. Seebeck found that "when two metals of unlike crystalline structure and conducting power" are soldered together and the junction either heated or cooled, an electric current flows across the junction, generally to the poorer conductor. Such is the statement of Professor Houston, who probably gives the law as later experimenters have expanded it, rather than as it was known to Seebeck, as it sounds very general and more comprehensive than it would be when announced after only a comparatively few experiments.

Later modifications of the thermopile — as the series of connected metals is called — have not essentially changed the principle, and it must be remembered that to Seebeck the credit of the apparatus is due, and that to him fairly belongs the invention of a wholly new method for producing an electric current. Besides being an independent invention, Seebeck's apparatus was another link in the chain showing that electricity was produced by a whole set of causes — and thus it helped men to understand that

they were dealing with a *state* rather than with a substance. We shall see later how each little invention based on a new discovery brought about a change in the understanding of electricity, that is, in its theory.

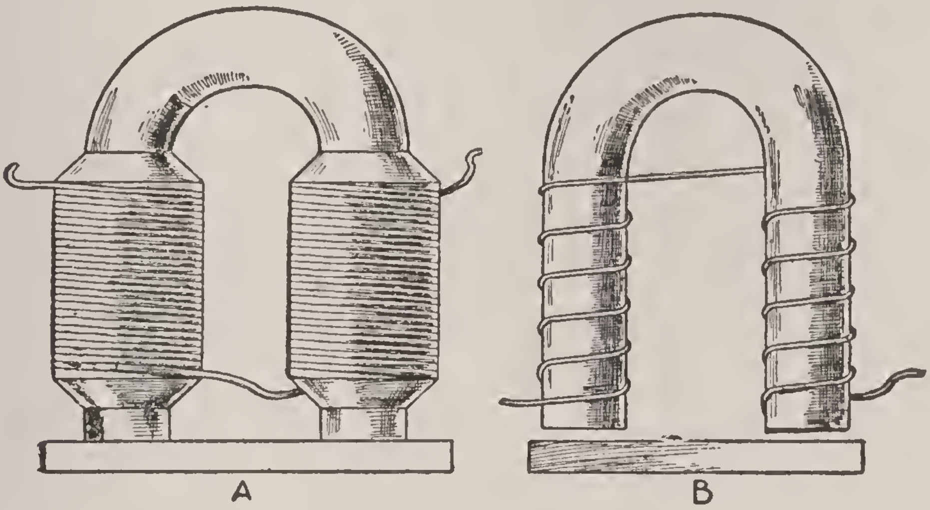
CHAPTER IX

THE ELECTRO MAGNET, THE MOTOR, AND INDUCTION

It will be noticed that nearly all the eminent workers in the new science of electricity were "professors," being connected either with some university or similar learned institution. This is the case with Galvani, Volta, Gray, Davy, Faraday, Arago, Ampère, Dufay, and others. While this may be in some degree due to the fact that these men had access to laboratories, libraries, and the records of other men's discoveries, yet there is another reason for their success. The science of electricity, as soon as it began to develop at all, was clearly understood only by men who could reason about things theoretically—that is, by using mental images, and by applying general laws mentally. This is the mathematical faculty,—another form of the constructive imagination already spoken of,—and these professors were men accustomed to that difficult kind of reasoning.

Electric action in or along a conductor cannot be seen, but must be followed mentally if practical inventions are to be made. The inventor has in mind a notion of the whole process, and then arranges real things to carry it out; or he notes an action that does not agree with his notion, and then makes guesses at the cause, and tries experiments until he has found the reason—new or old.

The next great step forward after the invention of the electric motor was the invention of the electro-magnet. This is due to two men at about the same time—Sturgeon of England and Henry of America. Arago had magnetized steel bars by putting them inside glass tubes about which a spiral of wire conducted electricity. In 1825, William Sturgeon, who began life as a shoemaker's apprentice, and, after a short time as a private soldier, became an investigator of electro-magnetism, made the discovery that soft iron when put inside the coil of wire instead of the steel bar was magnetic only while the current passed, losing its magnetism when the electricity is cut off. He also noted



MAGNETS—HENRY'S (A). STURGEON'S (B)

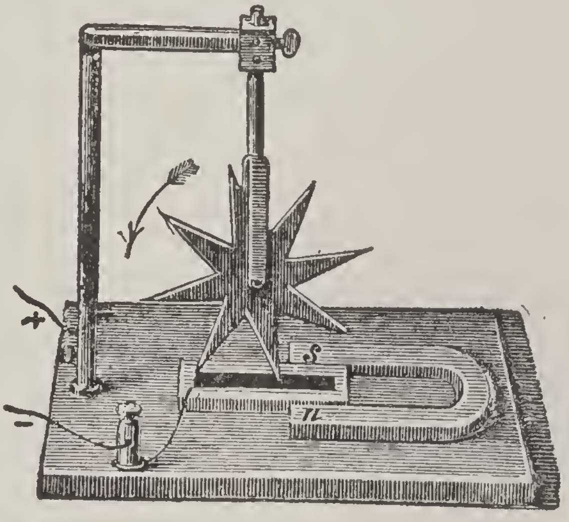
that the introduction of the soft iron core greatly helped the magnetic effect of the coiled wire and current. Since the iron core could not be called a magnet, not being permanently magnetized, Sturgeon called the whole combination an "Electro-Magnet." He also used the horseshoe form for the core. Thus Sturgeon had advanced upon Ampère's use of a steel core, by using a soft iron core in the coil.

Professor Joseph Henry completed the invention, and increased its value immeasurably by remembering the Schweigger multiplier idea. Schweigger used the multiple coils to strengthen the action of the current upon the deflection of a needle. Henry applied the multiple coils to strengthening the action of the current upon the soft iron core of Sturgeon. Beginning with the idea of studying medicine, Henry did occasional writing on scientific subjects and was appointed engineer to survey a road from the Hudson River to Lake Erie. This turned his attention to science, and he became in 1826 a professor of mathematics and physics in the Albany Academy, and the next year read his first paper on the "Electro Magnetic Apparatus." His great improvements were the use of insulated (silk-wound) wire for the coils, the use of multiple coils, and also—an invention based on his own discoveries—the use of a *single* wire wound spool-fashion when using batteries in series, and the use of a number of separate wires, each wound around the magnet, when the batteries were connected in multiple. The numerous coils were found to conduct the latter form of current more efficiently.

Henry's electro-magnets formed on these principles were enormously powerful for his time — one in 1830, lifting 750 pounds; one in the following year 2,300, and, in 1834, one lifted 3,500 pounds.

But before proceeding with the account of Henry's researches, there are still some important steps to be noted in the years from 1825 to 1830. In 1826, there was an improvement upon Faraday's motor in the apparatus of Peter Barlow, a professor in the Woolwich Academy of England. Barlow's invention as pictured

shows a flat board on which lies a permanent horseshoe magnet. Between its poles is a little trough of mercury, into which dips a star-shaped wheel suspended on an axis, supported from a frame. Electricity is conducted along the support to the wheel, through the mercury and back to the battery, causing



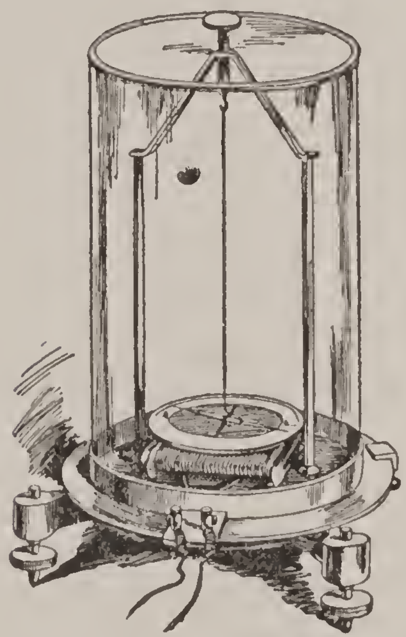
BARLOW'S INVENTION

the wheel to revolve. This form of motor was again changed by Sturgeon, who used a circular smooth edged copper wheel, and instead of the mercury used the contact of the conducting wires—one at the axis, the other on the edge. This was not satisfactory, the contacts being not always good. Both these little motors were only connecting links to better forms.

In 1827 there was announced by Dr. George Ohm, a German professor of mathematics, born in 1781, a most useful law for calculating the amount of electricity acting through a circuit in a given time. The law was based upon the researches of others, but has proved so useful that its discoverer is entitled to the fame he has acquired by having the unit of electrical resistance named the "ohm." It measures the diffi-

culty the current meets in getting through a conductor, just as friction measures the difficulty in turning a grindstone. Professor Houston states the value, roughly, of one ohm, to be "the resistance of two miles of ordinary trolley wire," or "the resistance at 45° Fahrenheit of *one foot* of No. 40 copper wire," which is a little over three-thousandths of an inch in diameter.

Ohm's law is briefly this: The strength of the current equals the electro-motive force divided by the resistance; or to substitute the electric names: The ampèrage equals the voltage divided by the ohms; and therefore: One ampère equals one volt divided by one ohm. To compare electricity with water flowing from a reservoir, the ampère is the unit rate of flow, the volt is the unit pressure caused by the height of water, and the ohm is the unit resistance or friction to the flow. The coulomb — another electrical unit, of *amount*, would be represented by the quantity of water that would be delivered in a given time under unit pressure and resistance. The full importance of Ohm's law was not recognized until about fourteen years later, when the Royal Society of England awarded him the Copley medal. But as the complexity of apparatus increases, the value of such helpful laws becomes more and more evident as they are applied to help in the solution of practical problems.



A GALVANOMETER

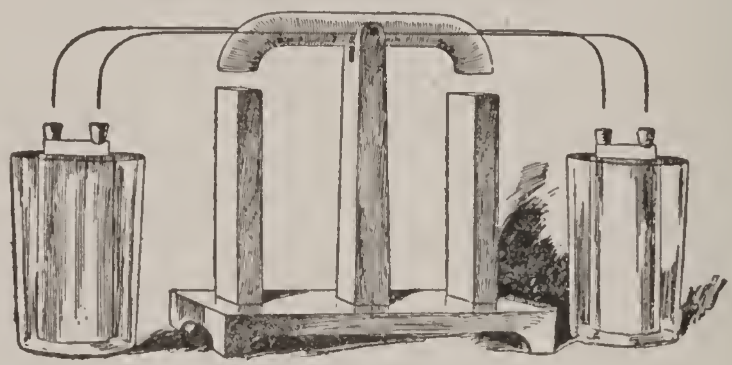
Used for the detection and measuring of currents.

Another very important event of the year was the exhibition, by Professor I. F. Dana, of Columbia College, of Henry's electro-magnet in a course of lectures on physics. Among Dana's audience was the artist Samuel F. B. Morse, who thus first saw in operation the device that was to make possible the telegraph instruments he afterward perfected. But Henry himself saw something of the possibilities of the electro-magnet as a means of transmitting power to a distance. In 1828, the very next year, he suggested that by means of an insulated wire an electric current could be made to operate his great electro-magnets as far as sufficient current could be carried, but the development of this idea was postponed until after the telegraph had reached a state of practicality. And this order of development was natural, since the conveying of intelligence was then even more desirable than to carry either power or material things.

In 1829, Becquerel made a new voltaic battery in which he used two fluids instead of one. He was a French physicist, born in 1788, an officer of Engineers who became a member of the Academy of Sciences. His double fluid cell was made by letting each element of the battery dip into a separate fluid, instead of both into one. The principle was perfected by an English electrician, Daniell, in 1836, and Becquerel is here mentioned only because he was, contrary to what is often stated, the first to suggest the use of the second chemical to absorb the gases liberated by the ordinary cells of zinc and carbon, though Daniell's cell was the first to make the suggestion practical.

In 1830 there was an attempt to construct an electric motor on a new principle. An Italian, the Abbé

Dal Negro, who was professor of Natural Philosophy in the University of Padua, hung a magnet on a pivot, like a pendulum, so that its lower end could swing while the upper end was between the poles of an electro-magnet. A current being sent through the magnet attracted the upper end to swing toward one pole. But as it swung, a rod tipped a little frame so that conducting points were dipped into mercury cups, and changed the direction of the current. Then the other pole of the electro-magnet attracted the pendulum top, the current was changed again, and so on. This method of getting motion was inferior to that used by Professor Henry in a little model motor still



PROFESSOR HENRY'S MOTOR

preserved in Princeton University, which he devised in the following year. Henry hung an electro magnet like a walking-beam or scales, and as it turned on its pivot caused it to dip two wires into two mercury cups on each side, closing a circuit first on one side, and then on the other. Below the ends of the horizontal magnet were two upright magnets, and as the poles of the beam magnet were changed, it was attracted alternately to one and the other.

But this continual change of motion, whereby motion in one direction must be stopped and then motion

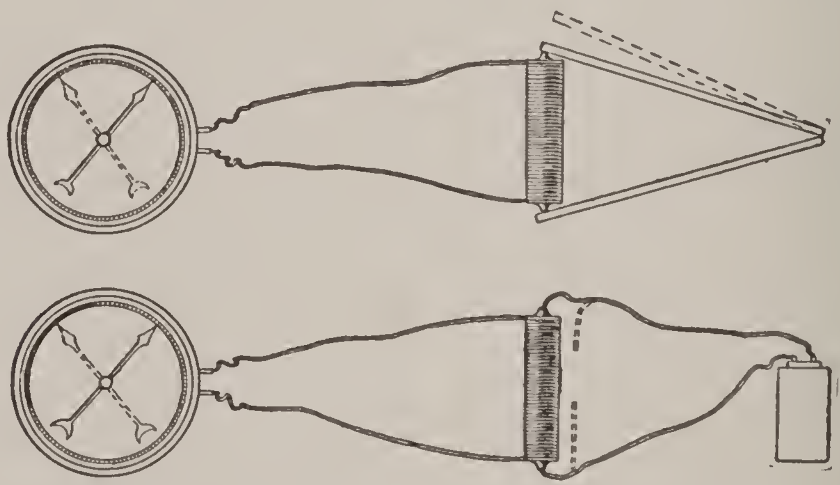
in the opposite direction set up, is not good mechanics, and so these swinging motors were not developed after the rotary motors were devised.

In 1831 Faraday, whom Tyndall called "the greatest experimental philosopher the world has ever seen," made a discovery of supreme importance. Oersted had shown how electricity might be made to produce magnetism, and as a consequence the development of the motor began ; for the voltaic cell gave electric action, the electricity set up magnetism, and magnetism made and unmade could be changed into mechanical work.

But Faraday was to show how magnetism could be changed into or made to give the electric current when a magnet was acted upon by mechanical motion. That is, he was to make it possible to convert motion —whether natural or artificial—into an electric current. This done, waterfalls, wind, steam power, animal power, or human power could be turned, as one may say, into electricity. Professor Houston says, "Faraday's discovery should indeed be ranked in importance before the discovery of Oersted were it not dependent on Oersted's."

Faraday, like others, believed in the possibility of getting electricity from magnetism long before it was done in practice. His earliest experiments were made with active currents, and no matter how strong these were, he failed to find indications of the induced currents he was seeking. But after many experiments he noted that whenever a circuit was made or broken, there was a slight movement of the galvanometer needle—that is a slight induced current was present in the circuit placed within the influence of

the active circuit. This slight induced current ceased as soon as the other current was at full strength or had entirely ceased. Observation showing him that this induced current was *opposite* to that of the *increasing* active current, and in the same direction with the *decreasing* current. It is during this investigation that Faraday wrote to a friend that "he thought he had a good thing," but that it might be "a weed instead of a fish." Next Faraday sought a means of causing the current to increase or decrease continually. He caused a coil of insulated wire to approach to and then to recede from an active current, and



FARADAY'S EXPERIMENT IN MAGNETIC AND VOLTAIC INDUCTION

found this was equivalent to shutting off or turning on the current. An induced current was thus produced in the insulated coil. The next step was to use a magnet in place of the active current, and this also produced the induced current.

The problem was solved, and it remained only to devise the best practical means for causing the continual production of the induced currents. But Faraday was usually content to leave minor invention to

others, knowing that his best work was done by looking for new facts and new laws.

Thus had Faraday established the principles of "voltaic-electric induction," and "magneto-electric induction," as he called the action, according to whether the current was induced by a battery or by a magnet. Thus he virtually founded modern electrical industries.

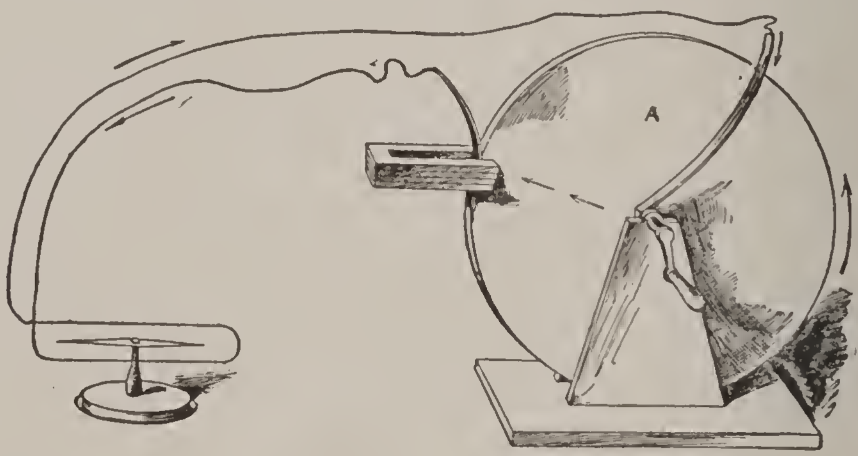
Once the principle was understood it was not difficult for so able an experimenter to secure the desired results in a number of ways. By using a large spool of insulated wire, hollow at the middle, and placing within this another spool in which was an active current from a battery, the induced currents were set up in the first coil whenever the second was inserted or withdrawn. Or, by leaving the small coil within the larger, and connecting or disconnecting the battery, the currents were induced—the inverse (opposite) when connection was made, and the direct (same direction) when it was broken.

With induced currents Faraday was able to perform the same experiments (with one exception) as with others however produced, thus proving their identity. The exception was the *chemical* effects; but at a later time he found that very rapid making or breaking was necessary to produce these; and the identity of the induced currents with those coming from machines, batteries, thermopiles, and any source was established.

Now that the principle is known, it is easy for any one to show the induced currents. For example, if a piece of insulated wire be coiled, and its two ends attached to a bit of iron, approaching or withdrawing a

magnet to the iron will move a compass needle within the coils.

From this discovery it was not a difficult matter to construct a little machine for producing electricity from a permanent or electro-magnet—that is to make the first *dynamo*. Faraday hung a copper disk or wheel upon an axle, and attached a crank for turning it, so as to make it revolve between the poles of a horseshoe magnet. Against the axle, and against the edge of the disk rested flat bits of copper, or *brushes*,

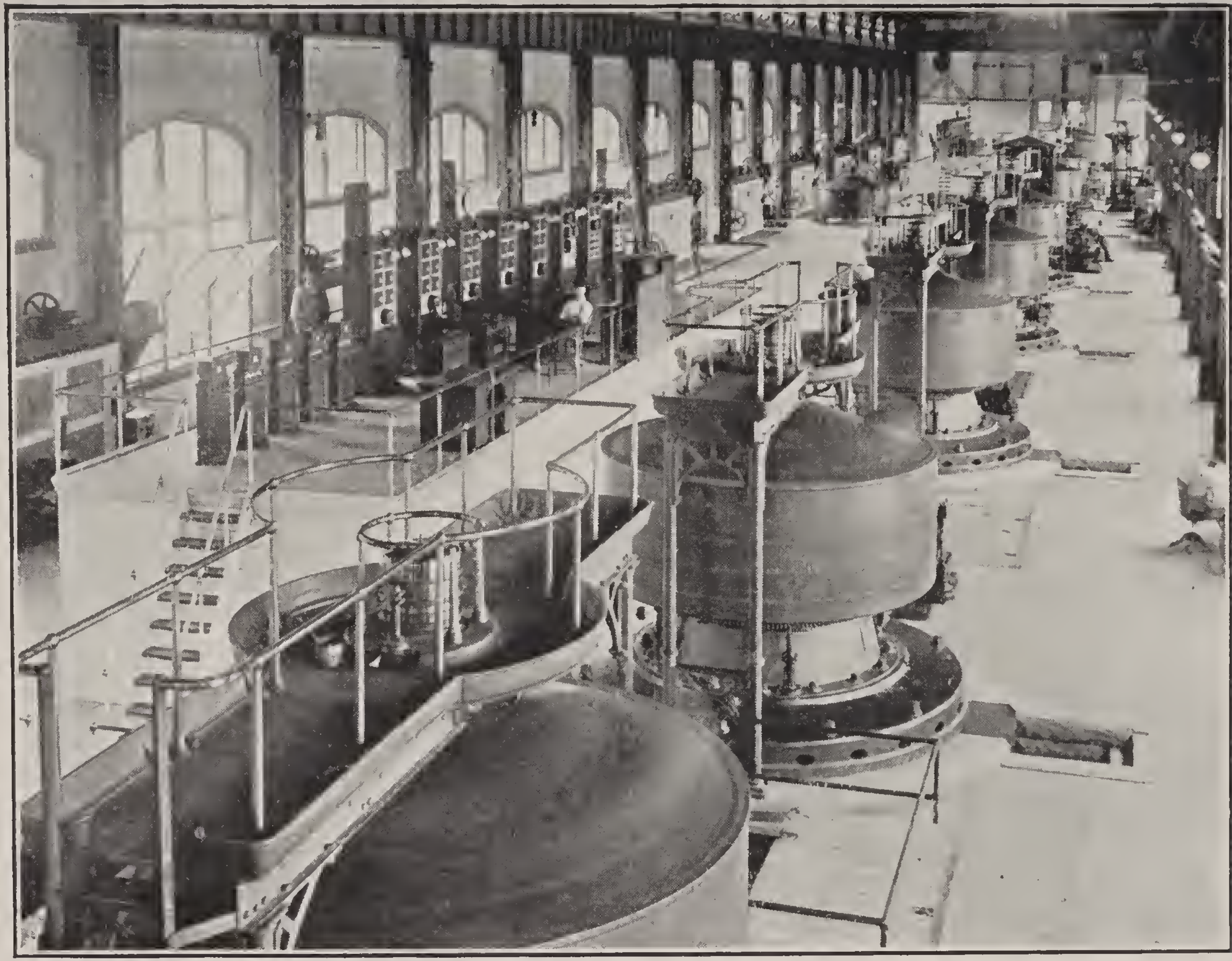


FARADAY'S DISC-DYNAMO, THE FIRST DYNAMO EVER BUILT

When the copper disc A is rotated from left to right between the magnet-poles, currents are set up in the direction of the small arrows and are taken off by the curved brushes.

to each of which was attached the end of the conducting wire. Turning the disk, an electric current was set up in the wire—as a galvanometer showed by the deflection of its needle. The baby dynamo was born, and soon began a growth that we cannot yet with certainty limit.

As to the explanation of its action, there are theories, but they are not yet certainly established. To state them is only to give the *law*, not the *reason* of the dynamo's action. In general it may be said



5,000 HORSE-POWER DYNAMOS, 25 REVOLUTIONS PER SECOND, 2,200 VOLT CURRENT, NIAGARA FALLS POWER CO.

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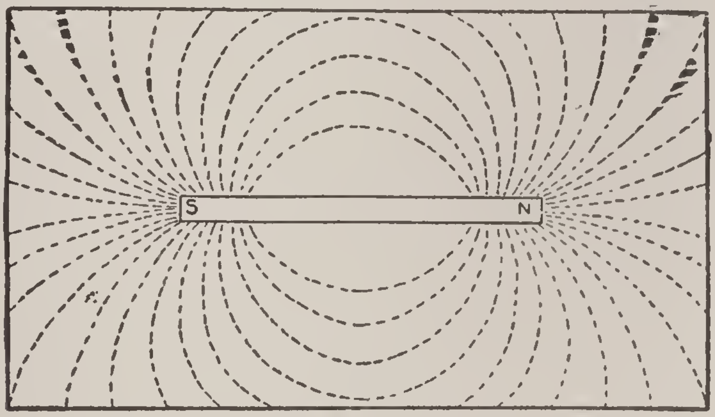
(*See also page* 255)

that by the experiment of strewing iron-filings near an electric current or an electro or permanent magnet, we find them arranging themselves in certain lines that have been called "lines of force." These lines are taken to indicate the situation in space of the electric and magnetic action, and they show the electric action to be in circular form about electric conductors and about magnets.



THE MAGNETIC LINES OF FORCE

Now when these lines of force are interrupted by a conductor, electric currents are set up in the conductor or around its surfaces. Consequently, when in Faraday's little disk dynamo the disk is turned between the magnet-poles, the lines of force between the poles are cut quickly near its edge, more slowly nearer its centre, and the conductor is electrified, a current is set up from edge to axis—and from it the conducting wires make a path for the current produced.

As to the production of the induced current, Professor Houston explains it by saying that as the live current *increases*, the lines of force increase in number, and extend outward around the conductor, thus being interrupted by the other conductor ; while the current

decreases, the lines of force decrease, drawing closer to the conductor, and are again interrupted by the other conductor.

Whether this explanation exactly agrees with the facts or not, it is at least a right way of considering the action, and enables one to think clearly of it.

In the same year of the birth of Faraday's baby dynamo, Professor Henry was at work in two directions that were of first importance. He is credited by some authorities with the independent discovery of the induced currents at the same time as Faraday. We have described his beam-action motor, but we have merely mentioned his first step in telegraphy ; but the early attempts at telegraphy will be told of in the next chapters.

CHAPTER X

FIRST BUSINESS USES

We have already said a word or two about Sömmering's multi-wire telegraph and there were a number of investigators and inventors besides, who had before this time made some steps toward an electric telegraph. These may be briefly noted in passing, but need not be fully described since their cruder methods were superseded by a better use of the same principles, or the use of new principles. The first idea was that of "sympathetic needles" that would move alike though at a distance from each other; but these, though spoken of, were not possible before the discovery of the action of the electric current on the magnetic needle. In the eighteenth century the multi-wire system was thought of, and was possible. An interesting fact is the publication in the *Scots Magazine* of Edinburgh, in 1753 of an anonymous letter describing fully the means of telegraphing through a set of twenty-six wires by causing each to attract a letter of the alphabet. The signature to this proposal was only the initials C. M., and many useless guesses have been wasted on the problem of discovering the author; and in 1809 came Sömmering's bubble telegraph. In 1820, Oersted's discovery made telegraphy possible, and as Professor Owen said, "Nothing might seem less promising of profit than Oersted's painfully pursued experiments with his little magnets, voltaic pile, and

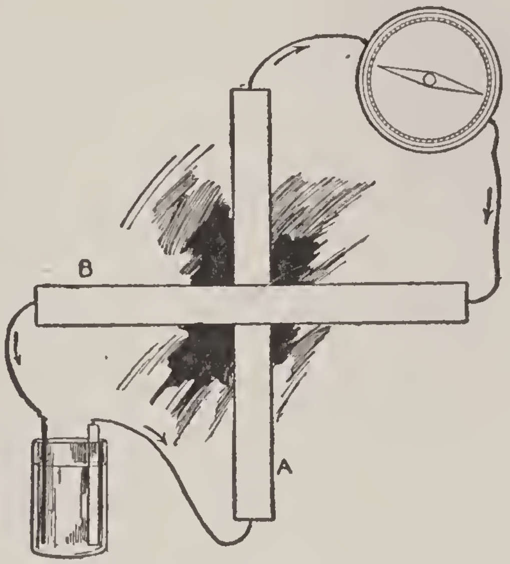
bits of copper wire. Yet out of these has sprung the electric telegraph." But neither Oersted nor Ampére ever seem to have made a telegraph line. Then came the Sturgeon magnet, and its improvement by Henry, and its application by Henry in 1831 to the giving of a signal at a distance. He arranged a bell so that it was struck by a rod, moved by an electro-magnet, and as is remarked in Byrn's, "Progress of Invention in the Nineteenth Century," "this may be considered the pioneer step of the telegraph." But credit should also be given for another discovery that helped to make telegraph lines practicable. This was the observation made by Weber, the German electrician, in 1823, that a bare copper wire carried through the air in Göttingen from his house to his laboratory, needed no insulation beyond being kept clear. Without this help, the establishing of long circuits would have been most expensive and troublesome.

We have already seen that Morse had heard from Professor Dana's lips the properties of Henry's magnet. In 1829 he had gone to Europe, and on the home voyage in 1832 began to consider the question of the electric telegraph.

But before entering upon this question, it will be well to say something of Morse's earlier life. Born in 1791 in Charlestown, Massachusetts, he entered Yale in 1805, and here received the instruction of Professors Day and Silliman in science. In 1811 Morse began the study of art under Washington Allston, with whom he went abroad, returning in 1815. From 1825 to 1845 he was president of the National Academy of Design. A second visit to Europe was made in 1829, and upon the ship *Sully*, he was informed by Dr.

Jackson, of Boston, of Faraday's experiments; and soon after, in a discussion with fellow passengers he set forth the general principles of the necessary apparatus for a telegraphic line, and showed sketches of it to his companions and to the captain of the ship.

Morse's invention at the time of his landing, was comprised only in his sketches, showing an electric circuit, a system of "dots or points, and spaces to represent numerals," and two ways of causing the electricity to mark these on a ribbon of paper — one by chemical action, the other by moving a lever carrying



The Peltier Cross
A—Antimony. B—Bismuth.

a pen or pencil. He also thought of moving the ribbon regularly by clockwork, and of burying the conducting line in tubes. Soon after landing in November, 1832, he planned and sketched the idea of carrying the line on posts. But his earliest model was not made until 1835.

Meanwhile in 1834, in observations upon the thermopile, it was discovered by an investigator named Peltier, a retired French watchmaker, that if a current

were sent through the two joined metals in one direction, the junction was heated; but that when the current was sent in the reverse direction, the junction was cooled. It will be seen that this bears a similarity to the changing of electricity to magnetism and magnetism to electricity, in that change of temperature of the junction of the thermopile, produces electric action, and electric action produces change of temperature.

Another experimenter, Lenz, succeeded in causing this "Peltier effect" to freeze water, and lower the temperature of its ice to twenty-four degrees Fahrenheit, or eight degrees *below* freezing-point.

Between 1831 and 1834, Faraday had drawn from his experiments the general laws governing induced currents. "Nothing," says the article in the Britannica, on "Electricity" (speaking of this law), "in the whole history of science is more remarkable than the unerring sagacity which enabled Faraday to disentangle by purely experimental means the laws of such a complicated phenomenon as the induction of electric currents." The general statement of the law is given in the same article as follows: "Whenever the number of lines of force passing through a closed circuit is altered, there is an electro-motive force, tending to drive a current through the circuit, whose direction is such that it would itself produce lines of force passing through the circuit in the opposite direction." Perhaps this can be more readily understood if we resort to the usual comparison of the electric current to a current of flowing water. Let us suppose a flexible tube inside which flows a current of water in a spiral course — thus

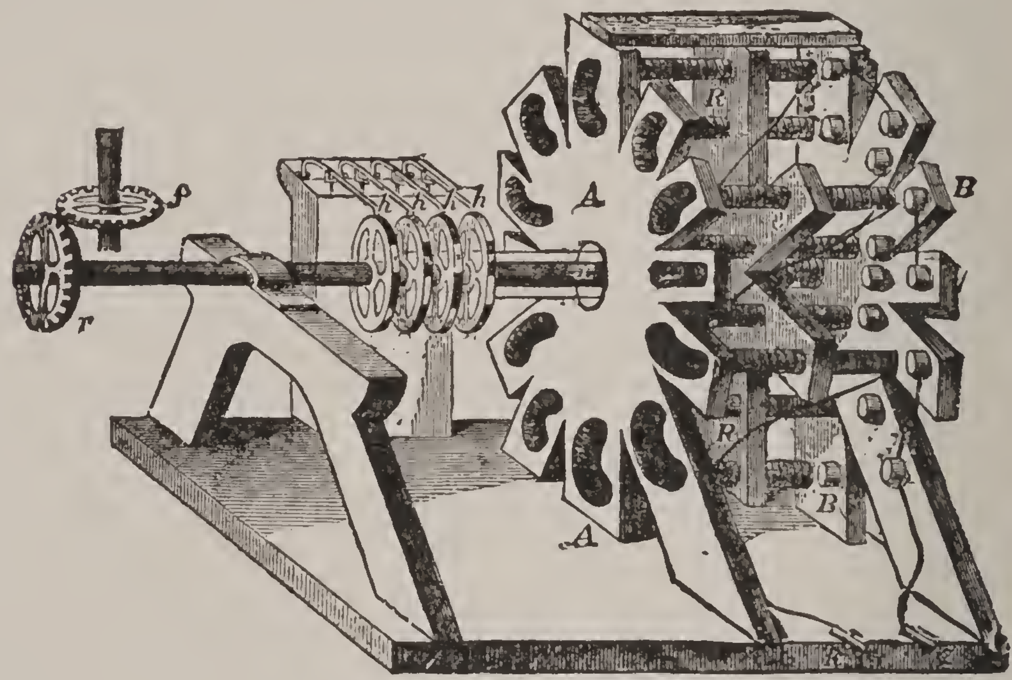
making it resemble in the lines of force the electric current. Now if we bend this tube into a circle, and then contract the circle to a smaller one, there will be a tendency to inclose more spiral lines of force into a smaller space, and there will be an increase of the current rate *in the same direction.* Then if we open out the circle, there will be fewer spiral lines of force inclosed, and it is as if the current rate decreased, or there was a *reverse* flow of the current.

It is not meant that this is a true representation of what occurs, but only a sort of mental picture helping us to remember the Faraday law. Lenz, the French experimenter before mentioned, added another expression of the law of induced currents, declaring that "In all cases of electro-magnetic induction, the induced currents have such a direction that their reaction tends to stop the motion that produces them."

After reading these laws, the non-expert reader will realize that we have been hastily going over a very great development in passing from the rubbed-amber attraction recorded by Thales to the general law of induction worked out by Professor Faraday. And yet the progress has been by successive steps, in which each pioneer hewed out a little clear space through the jungle of ignorance, and made thereby a road for his successors to extend still further. So general is the progress in these fruitful years that we are compelled to save space by making only the briefest reference to certain improvements in order that we may be able to dwell more at length upon the most important, remembering that many workers, all over the civilized world were busy in carrying forward

each form of electric apparatus, or in making new inquiries into the laws of electric action.

The motor, for example, when we next take it up, has assumed a rather complicated form. Sturgeon's smooth wheel developed from Barlow's spur-wheel, has been superseded by the rotary-motor of Moritz Jacobi, a multiplication of electro-magnets. Jacobi was a German who went to St. Petersburg in 1837, and be-

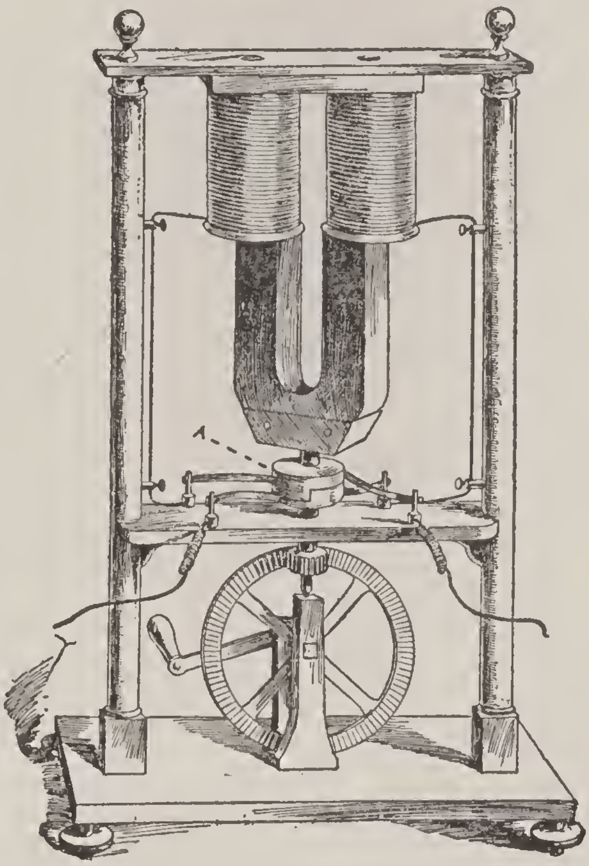


Jacobi's Rotary Motor

came a member of the Academy of Sciences, and later, councilor of state. He set up two wooden star-shaped frames each supporting twelve electro horseshoe magnets turned with poles inward (A, B). Between these wheel-shaped frames a turning wheel (R) carried straight electro-magnets, so that their poles were brought opposite those on the outer frames as the wheel turned. But, in turning, the poles of the inner magnets were changed as they came opposite the outer ones. This was done by *commutators*, disks (h) set on an axis, and so connected as to bring the electric current at one

part of the turn to one magnet, and then to another. Thus the inner magnets were first attracted, and then by a change of polarity, repelled by the outer magnets. The result was to keep the inner wheel spinning. At the end of its axis was a gear-wheel (*r*) to which machinery could be attached (*f*).

Improvement in the dynamo also had been made. Pixii, a French inventor, revolved a large permanent horseshoe magnet vertically beneath a fixed electro-magnet—thus inducing alternating currents in its coils as the turning magnet was brought near and then moved away. A commutator on the axis distributed the two currents to separated wires, thus making each continuous. It will be well to say a word of explanation about the commutator principle, as it is used in all cases of the kind. By placing on the turning axis a disk divided by insulating divisions into different conducting portions, these portions can be made to rub against conducting springs at different times. Thus, suppose an axis to end in a branched form like an upturned letter λ. We could arrange two springs so as to touch different branches of the λ at different times.



PIXII'S DYNAMO (1832)
(Note Commutator A.)

Then when a positive current was passing it would go to one spring so long as it was in contact. As the axis turned further, this positive spring would leave its branch, and the other branch would touch the negative spring while the negative current was passing. Then if conducting wires ran from each spring and were connected into a circuit, the current would always be sent in the same direction, since each end of the wire would be in contact with the axis only while its own kind or direction of current was coming.

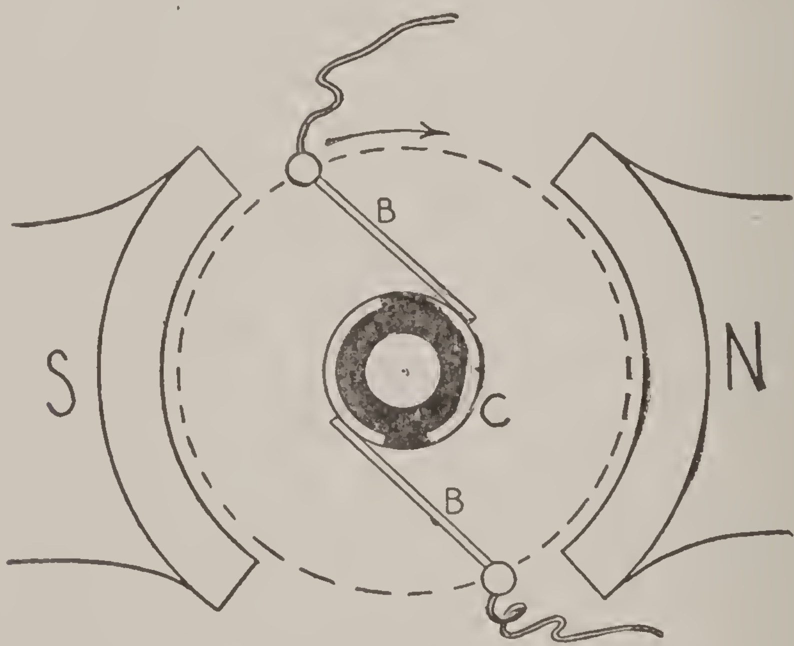


Diagram of Two-Part Commutator

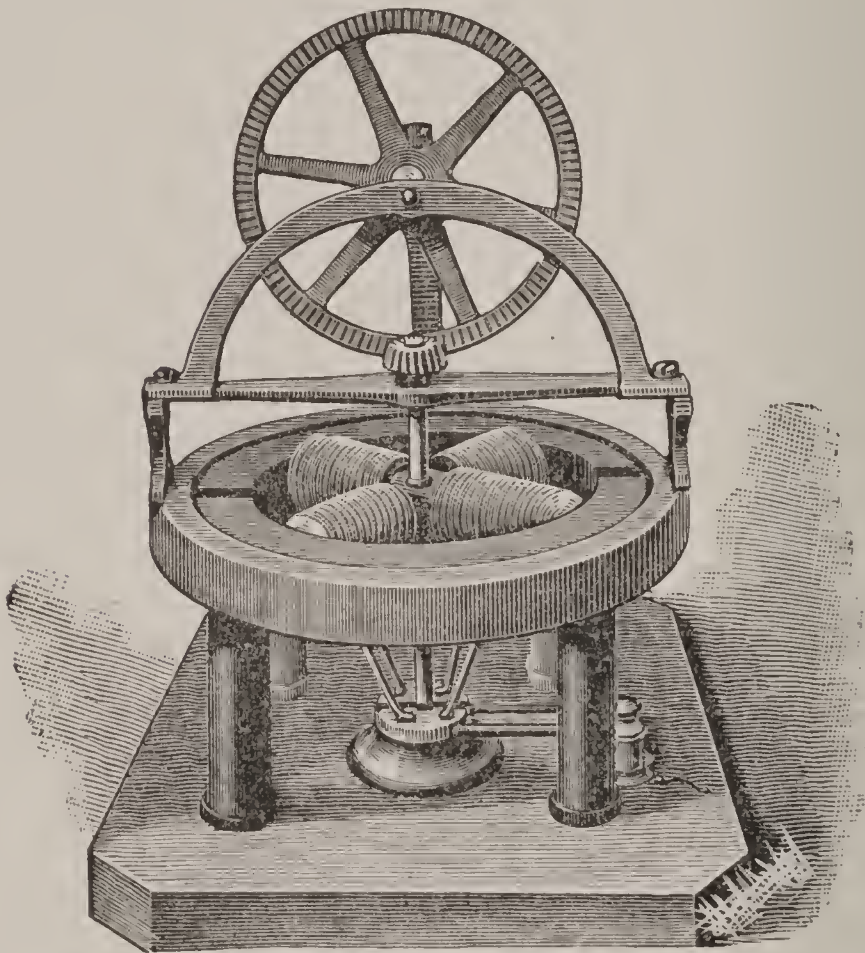
The commutator C mounted on a core of hard rubber insulation is attached to the axis of the armature, which revolves between the magnet-poles in the direction of the arrow. The brushes B B of spring brass, connected with the external circuit, collect the current from the commutator.

A split ring on an axis might be so arranged as to act in the same way, or two studs projecting—or a dozen other devices. This is the "changer" of currents, or commutator—a very essential and ingenious device, said to have been suggested by Ampère, adopted by Pixii, and improved by Sturgeon.

But to return to the motor. An improvement in Pixii's machine was devised by Joseph Saxton, an American inventor who rotated the electro-magnet instead of the heavier permanent magnet, putting the latter horizontally; and his device was bettered by Clarke, who, leaving the permanent magnet vertical, revolved the electro-magnet in front of the side of the poles on an axis going between them—which made the machine compact. He also wound the two poles of the electro-magnet oppositely, thus delivering an alternating current that the commutator made continuous or left alternating at will. This machine gave currents of more force than could be given by any single kind of batteries. The principle of Clarke's machine was some years later applied to electric lighting, as will be seen.

Within a year or two after this improvement of motors began, a Vermont blacksmith, named Thomas Davenport, invented a motor upon the excellent principle of revolving electro-magnets in the form of a cross within the circumference of two permanent magnets, each bent in a half circle and set in a ring form. This motor was so successful that it was used to operate a small circular railway at Springfield, Massachusetts, in 1835, and a few years later to run a printing press whereon was printed a little paper called the *Electro-Magnet.* Another American motor, invented by Ritchie, rotated the armature on an axis set within the U of the permanent magnet, as if a heavy-topped T were set into the U. But there is no need to go into all the modifications of these motors. All sorts of combinations were made, and gradually the better ones were retained and improved while the others

were abandoned. It is better to give some attention to the attempts to make these motors useful. Jacobi's motor was considered promising enough by the Emperor of Russia to induce him to spare the money for the construction of an electric boat, to be run by a bigger form of the motor. The boat was built and



DAVENPORT'S MOTOR

fitted with paddle wheels driven by the motor. It carried ten or twelve persons, and at times it ran for a whole day without accident. But at other times Jacobi was less lucky, and break-downs occurred that were difficult to repair. However, the electric boat went three or four miles an hour, and developed a fair amount of power from the battery of sixty-four cells.

On land, it will be remembered that Davenport had

already run his locomotive, driven also by voltaic batteries actuating his form of motor; and thus there were before 1840 distinct beginnings of electric locomotion on land and sea, but the cost of even the cheapest batteries was so great that the machines remained no more than the experimental triumphs concerning which the skeptical might ask *cui bono?*—"What is the use?"—not always receiving so clever a reply as Franklin gave to a similar objection when he asked in return: "What is the use of a baby?"

And truly these electric "babies" were being born at a rate that almost defies even a census of them within any fair space. The science was developing into specialties, and each of these was being pursued by an industrious group of workers; while at the same time those whose breadth of view enabled them to take in the whole field or a large part of it, were announcing the laws that made the work of specialists directed by right principles, and truly scientific. Faraday, whose work was invariably productive, had been experimenting with the electrical decomposition of chemicals by means of the apparatus now known as the "voltameter." Beginning in 1831, he made elaborate investigations that continued for nine or ten years and resulted in the discovery and declaration of the laws governing "electrolysis"—laws that have stood the test of time, but the reasons for which are not yet completely understood.

As these laws are fundamental, and aid us in understanding the progress of the science, they may be given here, although they may not be entirely understood in all their applications, until later inventions have been considered.

The general laws were announced in 1833, and are as follows: First at all points of a circuit,[1] the amount of chemical action is equal. Second, the amount of an "ion" liberated at an *electrode* in a given time is proportional to the strength of the current. Third, the amount of an *ion* liberated at an electrode in one second is equal to the strength of the current multiplied by the "*electro chemical equivalent*" of the ion.

The italicized words must be explained, and so must the action of a voltameter, and the reason for the name. First, a voltameter includes a means for passing an electric current through a conducting liquid, and for collecting the resulting products. It thus measures the strength of an electric current by measuring the amount of chemical decomposition it produces. The current from a battery is conducted by a wire into the liquid, and leaves by another which completes the circuit. Then the end of each wire is led into a glass test tube, or similar receptacle, inverted over it. By the use of such an apparatus, as has been said, Carlisle and Nicholson in 1800 decomposed water into hydrogen and oxygen. Later it was found that other liquids—such as dilute acids and solutions of salts of metals, could be likewise separated into their elements, and in every case the same elements always were liberated at the same pole. Faraday proposed names for the process and its results. *Electrolysis* is the process. The liquid is the *electrolyte*, and the wires *electrodes*. The endings are all Greek—meaning as follows: *lysis*, separation; *lyte*, thing separated;

[1] Professor Houston suggests that the circuit meant is a *simple* or *series* circuit, since the law as stated does not strictly hold for a multiple-series or series-multiple circuit.

odes, paths. Then to distinguish the two poles, he called the positive, the anode, or to-path; the negative, the *kathode*, or from-path.

Then, in order to explain the action, various theories had been made as to how the elements separated—a matter in dispute; but generally speaking it was thought that the atoms of one kind were set free more or less from their chemical bonds to the other kind, and wandered about. Faraday called these separated atoms, *ions*, meaning the go-ers or wanderers. Then to distinguish them by their goals, he named them "anions" and "kathions."

This will explain his laws as meaning that the action of the current is the same all through its course; that multiplying the current multiplies the action to the same extent; and that the *ions* liberated are always in proportion to their "chemical-electro-equivalent"—which signifies its *fixed* replacing power in combination with other elements. This is determined, and given in tables for use.

When it was known that the result of electrolysis for a given time, in a given solution with a given current was always the same, it became possible to measure currents as compared to one another. A current of twice the strength—or voltage—would do twice the decomposing in the same time, and this could be measured by *weight*. Hence the name "*voltameter*" or volt-measurer, for the apparatus.

This was another great step toward making the science of electricity an exact science, instead of guesswork. When in chemistry it was discovered that the elements always combined in definite proportions, the science of chemistry was born anew; and Professor

Tyndall declared that Faraday's discovery of these laws of definite electro-chemical decomposition was of equal importance. And we shall soon see how the discovery was followed by an improvement in voltaic-batteries—to speak only of one immediate result. Electro-plating, too, was at once put upon a scientific basis, together with the art of electrotyping—and the importance of these applications has been growing ever since.

CHAPTER XI

THE TELEGRAPH IN EARLY FORMS

The year 1835 saw, besides Davenport's locomotive, the establishment by Morse of the first experimental telegraph line. In that year the University of New York made Morse a professor, and he built a rude model of the telegraph in his apartments in the University Building. But, owing to the weakening of the current by the resistance of a long circuit, the working of the model was not satisfactory for any length of time. The batteries soon became weaker, also, by reason of the electrolytic action upon the copper plate which, decomposing the acid of the battery, sent ions of hydrogen to the positive copper, and these clinging to its surface prevented to some extent the action of the acid, and acted on the acid solution itself. These difficulties were both somewhat remedied by inventions of the year 1836, one made by Morsé himself,

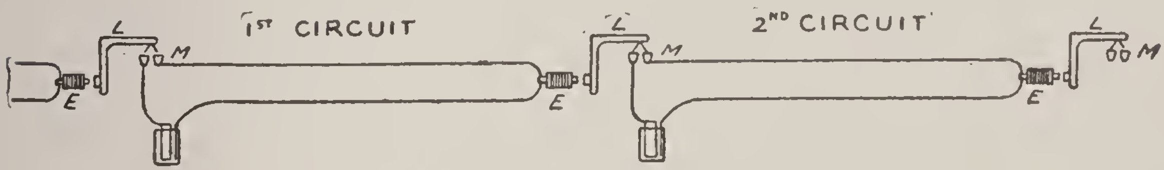


DIAGRAM OF THE RELAY PRINCIPLE
LLL—Levers. EEE—Electro-Magnets. MMM—Mercury Cups.

and other by Professor Daniell of London. Morse's invention was the telegraphic relay—a means for strengthening the weakened current in the course of the circuit. Daniell's invention was a better battery, one that removed the trouble caused by electrolysis.

The relay was thought out to answer the objection that his line would soon reach its limit of distance. Morse answered, "If I can succeed in working a magnet ten miles [away] I can go around the globe." But he knew an additional device was necessary to strengthen the original current, and between 1835 and 1837 he worked out the "relay." He reasoned that even much weakened, the current might have power enough to *close another circuit.* He therefore put a second battery at the end of the first circuit, and used the power of the first circuit to turn a little lever that dipped a bent wire into two cups of mercury, thus closing the circuit of the second battery. This could then send power on close a third circuit and so on.

The principle may be compared to a set of reservoirs at a distance from one another, and so arranged that the flow from the first will fill a long pipe at the end of which it raises a float that turns on a second reservoir, and so on.

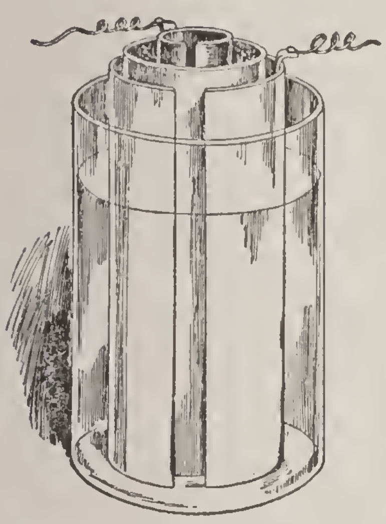
Of course the batteries could be opened or closed by sending impulses along the first circuit, if a spring is so arranged as to open each following circuit when the impulse is stopped.

Such was the means of supplying new current to a long line. As to the Daniell battery, this was a means of remedying not only the gradual weakening of the voltaic battery, but also of correcting its tendency to weaken, thus keeping the current at a nearly constant state.

Daniell was the son of an English lawyer, and after a classical education was so strongly attracted to natural science that he entered a sugar refinery, and made improvements in its processes. At the age of

twenty-six, he started a scientific journal that was conducted successfully for many years. He made many studies in meteorology—the science of the weather—and published able articles on the subject, and when he was forty-one became Professor of Chemistry in the new King's College, London.

His battery was based upon the principle of surrounding the copper element with a solution of bluestone or copper-sulphate. This, upon the coming of the hydrogen, decomposes, and the resulting chemical combinations with the hydrogen make two new substances. One is metallic copper, and this is deposited on the copper element, renewing its surface. The other is sulphuric acid which strengthens the acid solution in the battery.



THE DANIELL BATTERY CELL

This was a most ingenious method of converting a weakness into a source of strength; and the practical method of making up the cell was quite as remarkable. The cell was a glass jar, containing dilute sulphuric acid. A sheet of zinc was coiled into an almost closed cylinder, which stood in the sulphuric acid solution. Inside the zinc cylinder was a porous earthenware cup, filled with copper-sulphate solution; and standing in this was a similar nearly closed cylinder of copper. Then a porous basket of copper was put into the cylinder of copper, dipping into the copper-sulphate solution inside, and containing crystals of copper-sulphate.

Suppose a circuit to connect the copper and zinc

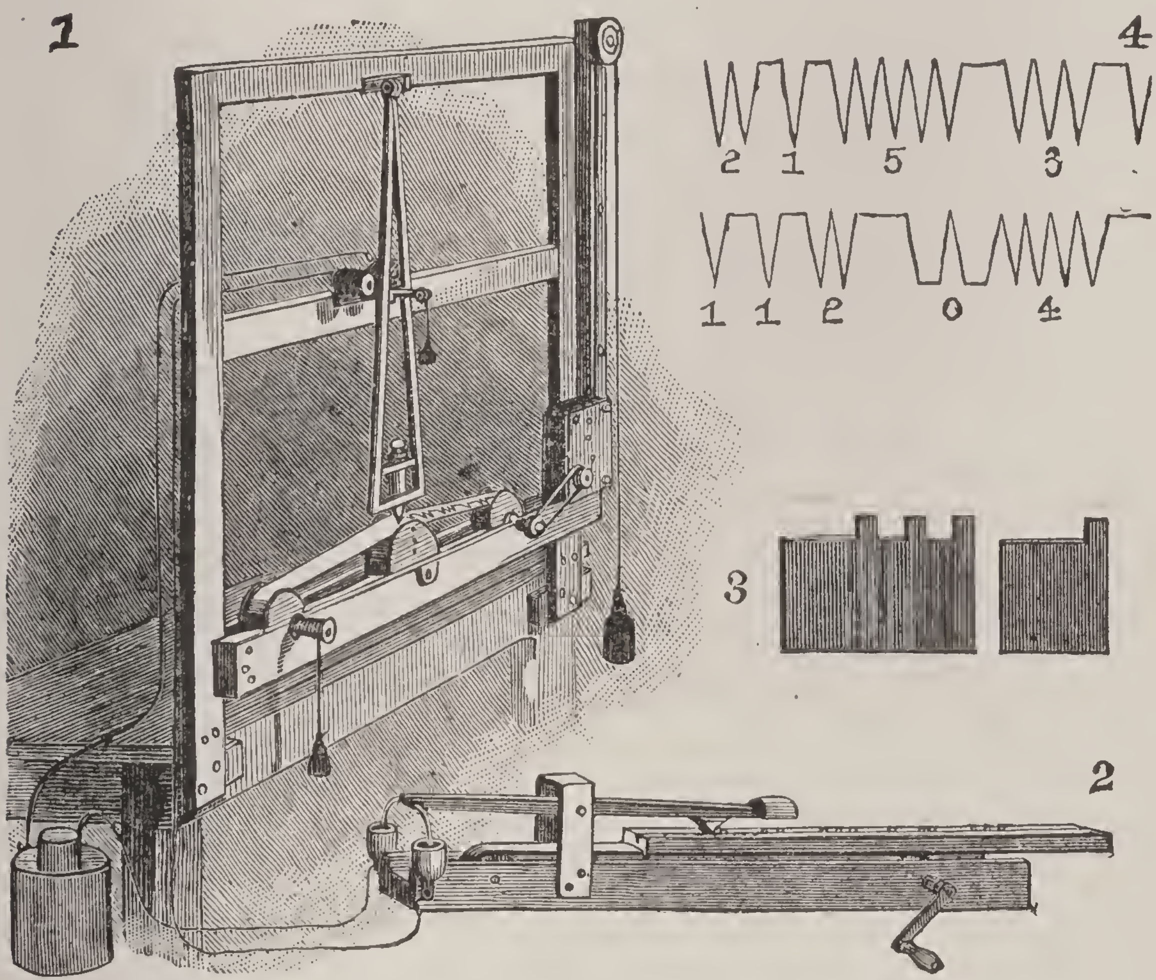
cylinders. The current then passes through the solutions, the zinc being acted on to form sulphate of zinc and to liberate hydrogen. The hydrogen passes through the porous jar, meets the copper sulphate, and combines with the sulphur, freeing the copper. The copper is deposited on the copper-plate, while the sulphur and hydrogen combine into sulphuric acid, strengthening the solution. As the copper-sulphate gives up its copper it is renewed by the copper-sulphate crystals in the basket. If there is a steady supply of the copper-sulphate and the zinc, the battery will keep up practically a constant current, for the copper surface is continually renewed. In brief form it may be said that the Daniell battery changes its waste products into the useful forms of copper and sulphuric acid.

As it is the current that determines what we may call the "circulation" of the chemicals in the battery, a Daniell cell should be kept in use to prevent a general mixing. But with slight attention the Daniell battery proved most effective, and particularly valuable to the infant science of telegraphy; and though we shall see that it had practical objections, these were relieved to some extent by improvements upon the original form at a later date.

The effect of the invention of a constant current cell was at once seen in a rush of improvements in telegraphy. Besides Morse, Steinheil of Munich, and Wheatstone and Cooke, in England, were early in the field with practical systems for sending intelligence. In 1837, Morse was able so far to complete and perfect details that he showed his apparatus to the professor of chemistry in the university, Leonard D. Gale, who

so fully appreciated its worth that he eagerly lent his valuable assistance; and on September 2 an exhibition of the apparatus was made before a number of spectators. Among these were an Oxford professor, and a young graduate of the University of New York, named Alfred Vail.

A 1,700-foot circuit of copper wire along the walls



MORSE'S FIRST MODEL—PENDULUM INSTRUMENT

1. Receiver. 2. Sender. 3. Type. 4. Message.

of a big room was the line, and Morse was able to make and record alphabet-signals instantaneously by means of his apparatus. This, though a crude enough contrivance compared to its followers, contained the same right principles that are still in use throughout the

United States, and most of the telegraph lines of the world. There were a sending and a receiving device, both connected in one circuit to which one voltaic battery supplied a current. The receiver was a square upright wooden frame, on which hung an A-shaped pendulum, to the lower end of which was attached a weighted pencil. Beneath this, touching the pencil, ran a paper-ribbon moved by clockwork. So long as the pendulum was still, the moving of the paper-ribbon caused a straight line to be drawn upon it. In front of the pendulum was an electro-magnet around whose coils the current passed. When the current passed, the magnet pulled the pendulum aside, and caused the pencil to make a V-mark in the line. Shutting off the current let a weight bring the pendulum to its first position. Thus every time the current was turned on a V was made in the line, at longer or shorter intervals. Such was the recording instrument.

Also in the same circuit was the sending instrument. This was a seesaw lever at one end of which a forked wire was held so that the ends completed a circuit when dipped into two cups of mercury, each of which was in connection with an end of the circuit. On pressing down the lever the wire connected the two cups, making a circuit.

The other end of the lever was weighted so as to break the circuit when the lever was released. On the under side of the same end was a point so fixed as to be raised and lowered by a band bearing projections on the upper surface. Morse had made lead types having such projections; and by setting these types in a groove, and by pushing them under the lever it was raised and lowered, making and breaking the circuit

according to the projections on the types. A type of one projection would make a V-mark on the recorder ribbon, one of two projections would make a V V-mark.

Thus the recorder could at will be made to mark a line, points, or spaces; and by a combination of these, Morse had designed numerals should be telegraphed.

A reason for the great value of this invention is the few elements that made it up, the simplicity of its action, and the permanent form of the record. It was telegraphy reduced to the lowest terms, and consequently could hardly be improved upon in principle.

The young graduate, Alfred Vail, was so strongly impressed with the great value of the invention, and with its possibilities, that he soon interested his father—a prominent iron-worker, who had made the shaft for the *Savannah*, the first transatlantic steam vessel. The elder Vail was told by Morse that the United States Government had issued through the Secretary of the Treasury a circular of inquiry on the question of establishing a system of telegraphy in the country, and he agreed to furnish the capital for making models, securing patents and showing the invention to Congress. Judge Vail, the father, had already been interested in the first American railways, and though it was a time of panic, he agreed to lend the necessary $2,000 on behalf of his son in return for an interest in the enterprise. Alfred Vail was to make and show the Morse apparatus, and to receive a one-quarter interest.

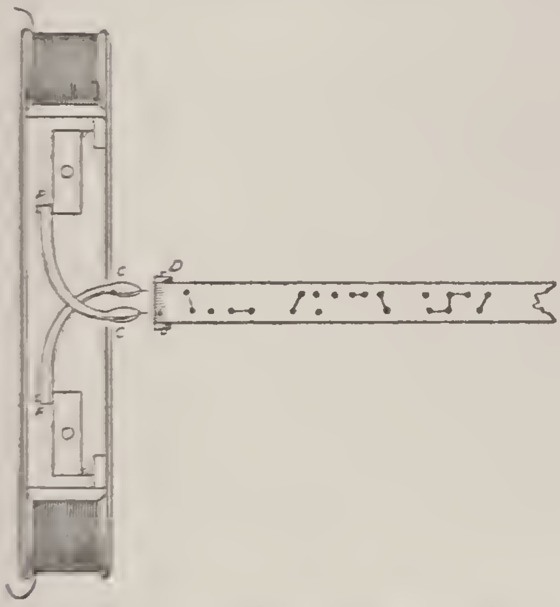
While Vail and an assistant constructed an apparatus in New Jersey, Morse prepared a description of his invention and filed a caveat at Washington to protect his invention. In this document it appears that

he had in mind the sending of numbers that were to be read by means of a dictionary of words represented by numbers. This plan seems to have been improved by Vail, who made the recorder lift and drop the pencil instead of pulling it aside, and who substituted dots and dashes for the V's, and indicated letters of the alphabet instead of numbers meaning words.

Also in this busy year occurred the improvements made by Steinheil in the original telegraph of Gauss and Weber. They had used, for a sender, in their line of one and a quarter miles, Faraday's principle of inducing a current by putting a magnet into a coil of wire; but they raised and lowered a coil that rested around a big bar magnet set upright. Their receiving apparatus was a heavy magnetic bar hung by a cord, and swinging horizontally in a square-coiled wire connected to the circuit. The needle or bar swung right or left when the sending-coil was raised or lowered. This movement turned a little mirror placed on the cord and reflected a spot of light to and fro along a scale. The mirror was placed so as to reflect the scale, and by looking through a little spy-glass, the signals could be read. It certainly was a heavy, clumsy, mechanical contrivance.

Steinheil to whom Gauss and Weber—who were more effective in theory than in practice—had referred their telegraph, was able to improve it in every feature. He made a stronger rotary sender, and for a recorder invented a clever arrangement by which the turning of two pivoted magnetic needles made ink dots upon a paper ribbon. The *principle* of the receiver, as will be seen, was not very different from Morse's instrument, though less simple. But Steinheil, in try-

ing to make use of the rails of a railway as part of a circuit, made a most valuable and helpful discovery —namely that instead of a return circuit, the earth might be used. Thereafter, instead of a double line, a single line with extremities buried in the earth was commonly used in telegraphy. This earth connection was not wholly new, since it had been used in all the telegraph lines that employed frictional electricity; but to realize that the earth might be used in complet-



STEINHEIL'S IMPROVED RECEIVER

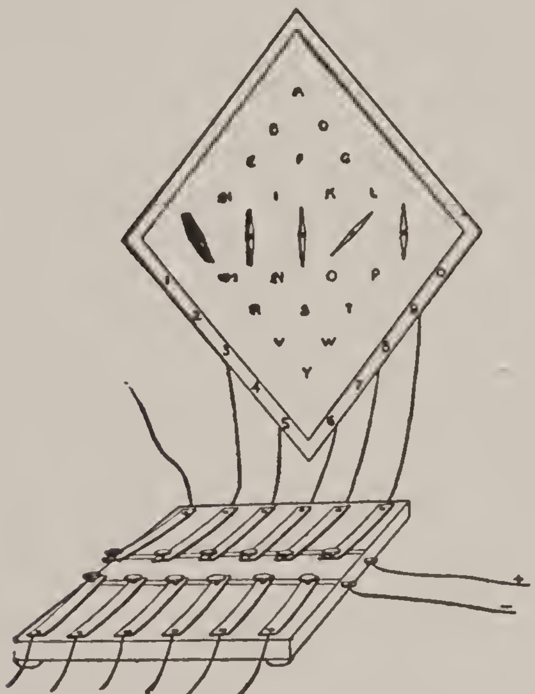
The capillary tubes CC carry ink from the reservoirs RR when actuated by the magnets, and strike the paper strip, which is unrolled by clockwork from the spool D.

ing a battery-circuit was another matter, and greatly simplified telegraph construction.

Suppose a telegraph line to be likened to a closed tube full of water flowing from sender to receiver and then back again; then suppose it to be found that the earth was full of water that could be admitted at one end of the tube and left to flow back into earth again, and you will have a good idea of the action of an earth circuit. Whatever is the cause of the disturbance known

as an electric current, it loses itself when brought into contact with the great earth as a river is lost in the ocean, thus leaving the remaining part of the circuit free to receive impulses from without.

In this year also was patented the telegraph apparatus of Wheatstone and Cooke—one based on the principle of deflecting a needle. Discovered by Oersted, this principle had been applied already by Gauss and Weber, improved by Steinheil, and by Schilling in St. Petersburg. Schilling's apparatus was a small keyboard like that of a piano. Each key when pressed could deflect a needle at a distance—right or left, as a positive or negative current was sent. Five needles thus gave ten signs, and these were combined into a code. William Cooke was shown this apparatus at Heidelberg, and returning to England was introduced by Faraday to Wheatstone, and the two together worked out an application of the deflected needles in 1837. It must not be forgotten that a number of other inventors were working on similar lines, and that only those who made practical instruments are here mentioned. Wheatstone was professor of experimental philosophy in King's College, London (Dan-



Cooke and Wheatstone's Instrument

The needles are actuated by coils placed behind each one, and operated from the keyboard. The letters and numerals are indicated on the dial by the convergence of two needles.

iell was in the same faculty), and spent his life in invention and research. Cooke was the more businesslike, and they worked well together.

Their first apparatus consisted of five needles pivoted on a vertical board that was diamond shaped. By means of a keyboard any of the needles could be deflected right or left, and when so deflected the letter indicated was found where the needle or needles pointed. If two of the needles pointed, the letter indicated was at their intersection—that is, where they would meet if sufficiently lengthened. This was the sort of apparatus described in their first patent, but it was later improved though with little change of principle. It was altogether far more complicated than Morse's telegraph, and so much more likely to be out of order at times. But even these did not exhaust the list of inventions of 1837; for in this year Vail, Morse's partner, suggested a printing telegraph —an idea that was afterward perfected in more than one form; there were several new motors; and a most delicate galvanometer, capable of measuring exactly the relative strength of two currents was made by Pouillet—one that is still in use. Savary discovered that the discharge of a Leyden jar was an oscillation, instead of a single impulse in one direction; a fact subsequently discovered and developed by the American, Professor Henry.

In fact, at this busy time the applications of the science were so many and so various that it becomes impossible to give attention to more than those involving some new or striking idea. Even the question of who invented a particular improvement becomes a difficult matter of the weighing of evidence and the

comparison of dates even down to weeks and days; and after we have done our best the credit may be unfairly awarded. In a recent discussion (1906) the question of the credit due inventors was the topic among certain eminent engineers, and the result, as stated by one of them, seems to be that the term "inventing" should be confined to the introduction of new principles rather than adapting known principles to "new situations and conditions." But—what is a "new principle"? Is it more than a very important and widely applicable idea? The best definition seems to mean only this; for it reads (Century Dictionary) "A truth which is evident and general; a truth comprehending many subordinate truths," and "in mathematical physics, a very widely useful theorem." But until the applications are made, how shall we know whether a theorem is widely useful?

In telling the story of electricity we can regard as new principles such only as have proved widely useful —as Oersted's noting of the deflected needle, and Schweigger's multiplying of coils around the needle; and we shall try to give chief importance to the applications that were forerunners of the devices we see in wide use to-day, but shall not forget that later development may make others as important.

CHAPTER XII

ELECTRICITY AT WORK

A MOST striking and valuable application of electrolysis was made in 1838. Before that date it was known that metals could be deposited on other metals or prepared surfaces by sending an electric current through chemical solutions. This as we said earlier was done by Brugnatelli, of Pavia; and De la Rive a Frenchman used the process for gilding wire in 1828; Bessemer plated lead castings with copper in 1834, and two years later De la Rue spoke of finding on the metallic coating of copper deposited in a Daniell's cell, "every scratch of the copper on which it is deposited." All these are cited by Professor Houston; but he says that no particular use had been made of these processes till, in 1838, Professor Jacobi (the same who made the boat motor) saw their possibilities as a means of making metal facsimiles of the surfaces on which the metallic coatings were deposited. In the following year an English experimenter named Spencer read a paper based on experiments during 1837 and 1838, in which he fully described the different *principles* of electro plating and electrotyping. Another independent inventor of the process was a printer named Jordan. Thus Jacobi, and Spencer, and Jordan appear to be claimants of the new art of electrotyping. The Britannica gives greatest credit to Spencer, and we shall briefly speak of his work.

Spencer said that he had used a copper coin in a Daniell battery, and found that the copper deposited on it came off showing a reversed copy of the coin—the projecting parts having left their shapes in the shell deposited. At another time, a little varnish being spilt on the copper element of a Daniell's cell prevented the deposit of copper where it adhered. Thus Spencer had found a means of depositing copper where he pleased and preventing its deposit where he chose. He applied these principles to a sort of engraving in relief. A copper plate was covered with a wax coating, and a design drawn, removing the wax along certain lines. Then the copper plate was etched—that is, put in an acid bath that acted on the exposed lines, eating into the copper. Next the copper plate was put into the voltaic cell, and copper was deposited along the roughened lines only—the wax preventing action elsewhere. The plate was taken out, the wax melted off, and the lines stood out in relief.

To make a plate directly from an *engraved* plate, he had only to deposit a copper shell upon it, and the shell, when stripped off, showed the engraved lines of the original plate, but in relief. He made other applications of the process, and an especially valuable one by making moulds of clay or plaster, on which by covering the surface with bronze powder or gold leaf he could deposit metal, forming a mold.

These methods, modified, form the foundation of modern electroplating, electrotyping, and electrocasting.

In 1838, Morse secured for his telegraph-system a French patent, having already applied for the American patent, and having petitioned Congress for an ap-

propriation to build a line long enough to prove the practicality of his apparatus. But his foreign voyage was a failure. The British refused his application on the ground that his invention had already been published; and Russia also refused him any help. The French government, though allowing his patent, is said to have appropriated his invention without compensation, and he returned to New York after about a year's absence — there to await the meeting of the next Congress in the United States. Altogether, he had so far pursued his purpose in spite of poverty, neglect, and lack of powerful friends.

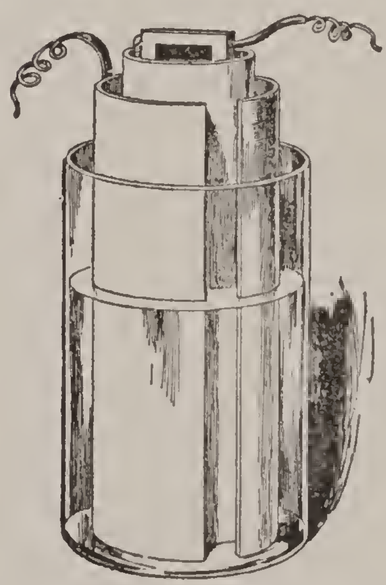
In 1839 an experiment had been made in electric propulsion by a Scotchman named Robert Davidson. He made a motor that drove a locomotive at four miles an hour over a rough plank road, using a 40-cell battery; but like all attempts to make use of the voltaic cell for the purpose, it was an economic impossibility to compete with other cheaper forms of power. Another event of this year that helped to bring electricity more prominently before the public was the blowing up of the wreck of the *Royal George* — the vessel celebrated for having turned turtle, going down in harbor with Admiral Kempenfeld and a thousand men aboard, of whom about 800 were lost.

This happened at Spithead, in 1782; and for over a half century the wreck had been an obstruction. Upon her sinking Cowper wrote his well known poem, "Toll for the brave, the brave that are no more!"

In hope of saving the vessel many attempts to raise it were made, but in 1839 it was decided to blow her to pieces. Cases of gunpowder were lowered into the

vessel and then exploded by means of an electric fuse. This fuse in its earliest form consisted of two insulated copper wires twisted together. Their ends were connected by platinum wire of very small diameter. The current meeting with great resistance in passing from the broad copper to the narrow platinum conductor heated the platinum sufficiently to ignite the powder. This elementary form has since been greatly modified, and instead of using a voltaic cell current, in such an igniter, a high-tension induction machine, operated by a crank or plunger has been found preferable for producing the explosion of blasting charges or for igniting gases and similar purposes where quick and great heat is needed.

The year 1840 saw the invention of a new form of voltaic cell known as the Grove, from the inventor, William Robert Grove, a graduate of Oxford and a lawyer, born in 1811. He studied electricity and became Professor of experimental philosophy at the London Institution. He is known chiefly for his learned book on the "Correlation of Forces," and also became distinguished in his profession, being knighted about 1872. Grove's battery was an attempt to improve on the Daniell cell, and substituted platinum and zinc for the zinc and copper. The platinum was dipped in nitric acid, surrounded by a porous cup, while the sulphuric acid and zinc plate were outside. Hydrogen liberated by the zinc was oxidized in passing through

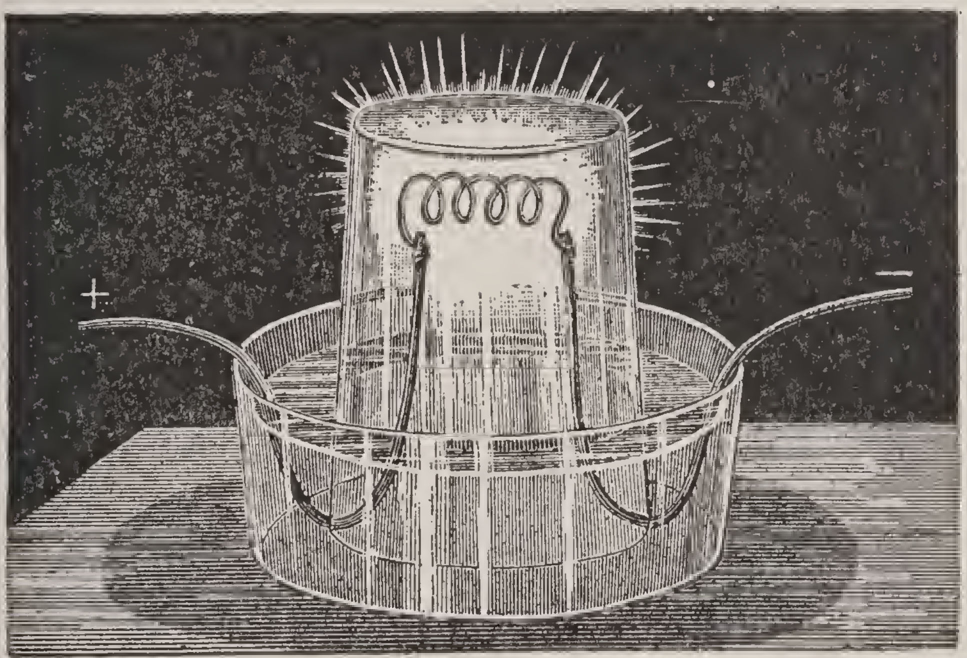


THE GROVE AND BUNSEN CELL

the nitric acid, the resulting combinations being part water and part nitric peroxide gas. This gas was dissolved in the nitric acid, and so there was no "polarization" or deposit on the platinum. The Grove cell furnished a powerful continuous current.

Within about two years, however, this battery was modified, at Grove's suggestion, into the Bunsen battery.

But to Sir William Grove belongs the credit for a most important pioneer step taken in the same year, no less than the first incandescent electric lamp. It was described in the *Philosophical Magazine* in 1845, and consisted of a bit of partly coiled platinum wire attached at each end to the bared ends of copper



GROVE'S INCANDESCENT LAMP, 1846

wires from several of his own voltaic cells. Upon the passing of the current the platinum wire was heated to incandescence, and gave a light by which he could read or carry on experiments for several hours.

Of course this was merely a "laboratory" device, being expensive, of short continuance, and entirely dependent upon the voltaic battery current, which was still far from perfected. The platinum wire as he used it was covered by an upturned glass, resting in another glass vessel — so as to exclude the air, and thus to prevent the rapid consuming of the platinum, and in his account of the light he noted the possibility of putting the platinum coil into a closed glass globe.

It was in 1840 that Morse succeeded in obtaining his United States patent. It was issued June 20, and numbered 1,647 — a number that is instructive in view of the high numbers we see attached to patents of our own day! — there being 650,000 granted even so long ago as January 1, 1900. But Morse's real triumph did not come until four years later, after the experimental outdoor line was put into working order, and meanwhile he was put to great straits to make a living. In 1840, also, Cooper of England, suggested the use of carbon to replace copper in voltaic cells.

The following year saw the first electrotype plate made for printing and used by an American, J. Adams, and also another platinum incandescent light made by Frederick de Moleyns of England, but no immediate practical use followed for the same reasons that prevented the use of the device of Sir William Grove — the expense, the irregularity of current, and the liability of the platinum to melt if for any reason the current raised it to a higher temperature than would give the white heat desired. Professor Wheatstone in this year took out a patent for a device that was greatly improved at a much later time. This was a printing telegraph — one that was to print its message in the reg-

ular alphabet. This was to be done by using the current to bring about contact between a strip of paper and a wheel on the edge of which were the type letters. The wheel revolved so as to bring the right letter over the paper, and then a current was sent through the line to press the two into printing contact — as in a modern "stock-ticker." But this mechanism did not come into use. The year 1842 was especially notable for the researches into new fields of theory. Professor Henry — who as an original worker was hardly less successful in practical discoveries than Faraday himself, succeeded in studying out and clearly explaining a problem that had proved something of a puzzle. This was the occurrence of what was known as "anomalous magnetism." When a steel bar is placed inside a coil through which a Leyden jar is discharged, it becomes magnetized, but in a most remarkable fashion if the discharge is sudden, as the bar is found to contain alternate layers of opposite magnetism. This may have been discovered by filing magnetized bars into shape, and was shown by Henry to be due to the fact that the discharge of a Leyden jar is really a rapid interchange of opposite currents — a vibrating back and forth of currents, each of which acts upon the steel bar. But the science of magnetism may fairly be considered a separate branch of electric theory, and is a study in itself not to be included in so general a survey as we must permit ourselves.

Henry also in the same year discovered the oscillatory — or to and fro — nature of the electric discharge. This had been shown in 1837 by Savary, but Henry went further, proving that waves in the ether were

set up at the same time — a very early hint of the most modern theories of electricity. Henry also constructed induction coils — an application of Faraday's experiment on induced currents but probably based on his own discoveries, and original with Henry though Page of Washington had made them in 1838.

In fact, to appreciate fully the place of so great a man as Henry in electric science it is necessary to study deeply into the science and the theory of the whole subject. He was "by general consent the foremost of American physicists," and the list of his achievements covers an enormous range of scientific subjects.

The induction coils must be explained as they play a large part in the present day applications of electricity to daily needs. Starting with Faraday, Page, and Henry, there were numerous forms of apparatus made with one general purpose, namely to change the nature of currents, in amount or in intensity. Once more resorting to the comparison with water, we may say that it is as if we used a reservoir of water to send a supply to another point, and there either to furnish a large amount at a slow rate of flow, or a smaller amount at a swifter rate of flow. By means of induction coils, a current of electricity can be changed in intensity. The method of doing this is as follows: The current is made to flow through a coil of wire, and this coil is used to induce a current in a second coil of wire. If the first coil has wire of few turns and large diameter the current meets slight resistance. If the second coil has many turns and wire of small diameter, the resistance is great. Now remembering the rule that current is proportional to the electro-

motive force divided by resistance ($C=\frac{E}{R}$)[1] or ampères$=\frac{\text{volts}}{\text{resistance}}$ we shall see that as the resistance is greater, the current decreases in volume but increases in intensity. Thus the new current becomes one of small volume and high pressure.

This condition, of course, is reversible. If the secondary coil has the larger wire and fewer turns the induced current is decreased in pressure or electromotive force and increased in volume. It is as if we made a river flow through a channel of varying width; where the channel is narrow the rate of flow is quick, where it is broad, the rate of flow or current is slow — though the same amount of water passes a given point in either channel in the same time.

The induction coils are sometimes known as "transformers" and called "step-up" or "step-down" transformers according to whether they increase intensity or diminish it.

The actual instrument especially designed for this purpose was invented in 1842 by Masson and Breguet, though afterward (in 1851) greatly improved by an instrument-maker after whom it has been named the *Ruhmkorff Coil.* A primary coil of wire, of large diameter and moderate length is inserted in the middle of a secondary coil formed of wire of fine diameter and many turns. Each coil is of insulated wire, and the two coils are insulated from each other. Inside the primary coil is a soft iron core, a bundle of thin wires being used. This core helps the action of the apparatus, and is also used to interrupt the currents, as will be seen.

[1] This is now usually written $I=\frac{E}{R}$, I being the symbol for current intensity in ampères.

It will be remembered that induced currents are formed only while the primary current is increasing or decreasing, or while it is being made or broken. So there is a little lever or spring key so arranged that it is moved whenever the soft iron core is magnetized by the primary current, and, being moved, breaks the connection of the primary current. This

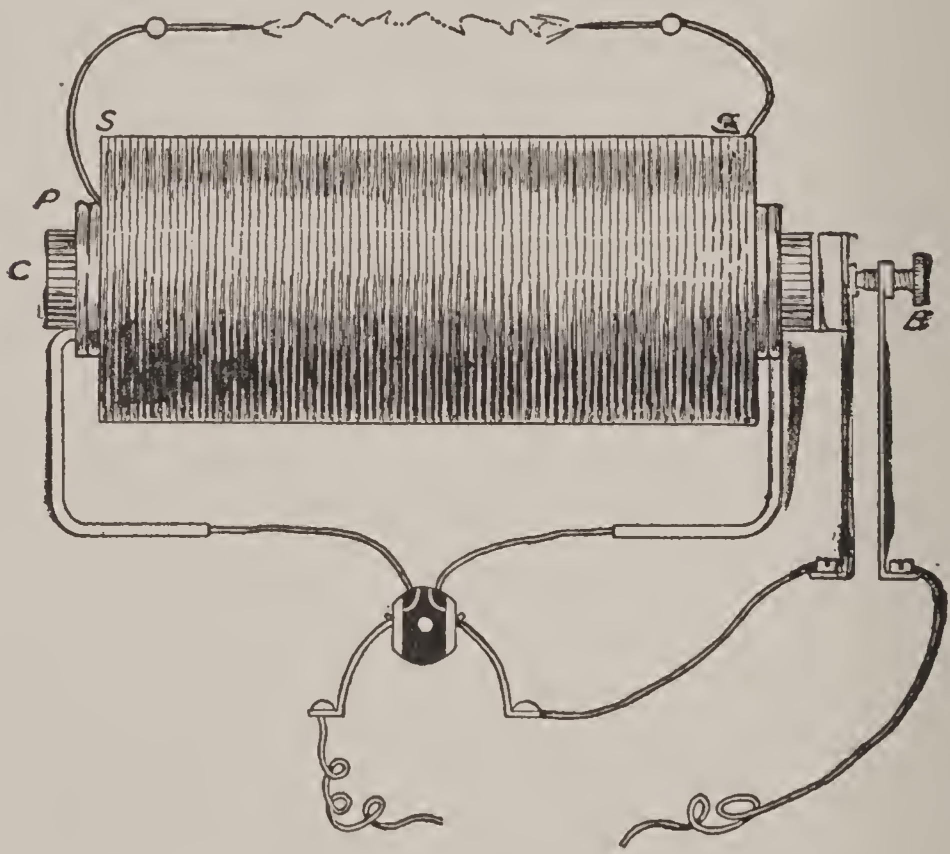


DIAGRAM OF THE RUHMKORFF INDUCTION COIL
C—Core. P—Primary coil. S—Secondary coil. The device at the right B is employed for rapidly and automatically breaking and making the circuit of the primary coil.

current breaker produces a continual making and breaking of the primary current thus: A current is sent from a battery through the primary coil. It induces a contrary current through the secondary coil. The core is magnetized. The core moves the lever, shutting off the primary current. This induces a second current (opposite to the first induced current) in

the secondary coil. The magnet acts again, and so on, the interrupter being so rapidly vibrated as to give out a musical note.

Attached to the instrument also is a commutator, by means of which the direction of the primary current can be changed from positive to negative, or shut off at will.

There are also other means of changing the electromotive force of the induced currents, but these may be left undescribed here. But it should be explained that the inductive action in the primary coil itself produces *extra currents* opposite to those coming from the battery whenever contact is made. These oppose the establishing of the current sent, and strengthen the reverse current set up when the current is broken. This makes the current at the breaking stronger than at the contact, and this current sends a strong spark between the ends or terminals of the secondary coil — usually two brass knobs separated more or less.

The current given from the secondary coil can be increased or diminished by having the primary movable within it — thus allowing it to be more or less influenced. The same effect is at times produced by inclosing the inner coil in a copper tube or *shield*, that can be more or less interposed. When in the way it interrupts the induction, by what Atkinson (in "Electricity for Everybody") calls "an electric eddy current," which is of course derived from the primary and lessens it by acting against it.

In 1842 also Morse made some experiments in New York harbor in order to test the possibility of using a current through the water. One moonlight night he went in a rowboat from the Battery to Governor's

Island, unrolling an insulated wire as he went, and succeeded in sending signals between these two points, thus convincing himself that "submarine telegraphy" was at least possible. But unluckily a passing vessel hooked up the wire on her anchor, and broke it off.

At this same period there was a great deal of most valuable work done by the workers upon the theories underlying the electric action. For it will be remembered that workers now had in their hands a number of instruments by which they could tell the force, the volume, the direction, and the presence or absence of the electric charge and currents. Among these workers may be named William Thomson — afterward Lord Kelvin, Helmholtz, and especially J. Clerk Maxwell.

William Thomson, born in 1824, distinguished himself as an original thinker even while still a student, and in 1846 became Professor of Natural Philosophy in the University of Glasgow. Even before this, in 1842, he had published valuable researches upon electricity. We shall see him credited with most useful discoveries and inventions all through the development of the science, and he is still actively interested. Hermann Helmholtz, three years his senior, was Professor of Physics in Berlin, and died in 1894, equally distinguished for his work in physiology, mathematics and physics. Maxwell, a Scotchman born in 1831, was writing scientific papers at the age of fourteen, was distinguished at Cambridge, and in 1871 was Professor of Experimental Physics at that University, dying in 1879.

Of all the investigators into the nature of electricity and its laws, he is easily first, his work being the "classic" on the subject. This was published

under the name "Electricity and Magnetism" in 1873. Of course he was still a boy at the time we are now considering, but is mentioned here merely to group the names of some of the more prominent theorists as a reminder of the work that was being done in laboratories for the aid of the more practical, workshop achievements.

It is hardly possible that any man should accomplish equal results in both theory and practice, and it is most unfair that the maker of the machines should become famous, while the thinker who has made the machine a possibility remains unknown except to scholars. When in reading books on Electricity we see references to "laws," or "principles," or "theorems," we must not forget that to construct these is often much more difficult and even more practically useful than to apply them to a single apparatus.

For example one of the most useful investigations to electric science was carried on from 1840 to 1889 by the English physicist, James Prescott Joule, who was a fellow worker with Thomson. In 1843 he proved that the mechanical and the heating power of the electric current were proportional; and in the same year showed that the quantity of heat needed to increase the temperature of a pound of water by one degree Fahrenheit is equivalent to the energy that will lift 772 pounds a foot. This law announced in 1843 became known as "Joule's Law," and enabled experimenters to measure electricity in mechanical terms, for he had shown in 1840, that the heat caused by a voltaic current in a metal conductor may be calculated by multiplying the resistance into the electric current, *squared*, and this into the time in seconds the current

lasts. To put it in a formula, Heat = Current (squared) × Resistance × Time, or $H = C^2Rt$. This formula gives the number of *units* of heat, and as the unit of heat has been fixed at the amount necessary to raise 1 gramme of water to 1° Centigrade, we simply multiply the number of units of heat by this value, and have an exact value for the results of the formula.

CHAPTER XIII

MAKING THE SCIENCE PRACTICAL

During the early days of 1843, Professor Morse was still struggling along in the hope of securing aid from Congress for which he had applied in the previous December. In March there was no action until the very last day of the session, when the bill was passed appropriating $30,000 for the work of an experimental line. Morse declared "this was the turning point in the history of the telegraph. My personal funds were reduced to the fraction of a dollar, and had the passage of the bill failed there would have been little prospect of another attempt on my part to introduce to the world my new invention."

Morse and Vail at once went eagerly to work building the line from Baltimore to Washington, and also making the hundred and one experiments needed to adapt the idea to actual use. In these, Vail's work was most important, and has not been sufficiently recognized, possibly in fear of diminishing the credit due to Morse. Vail invented a circuit breaker (like that on the Ruhmkorff coil) and an instrument for measuring current-strength, besides many minor improvements.

The laying of the line was attended by great difficulties, the wires being put under ground. After ten miles were buried — the line suddenly failed to work. The inventors and contractors were in despair, holding daily consultations. Out of $30,000, all but $7,000 was spent, and of this the contractor of the line claimed $4,000. This man was a member of Congress

named Smith who had entered the partnership. Disunion and trouble set in and the year ended in complete discouragement. It seemed as if all the appropriation was to be spent without even completing the line, and Mr. Smith was threatening to oppose the granting of a new appropriation.

Abroad, the year was marked by an invention made by Professor Wheatstone and Professor Jacobi, independently — a means of readily varying at will the resistance of any electric circuit by introducing an apparatus known as a rheostat. This in its early form was

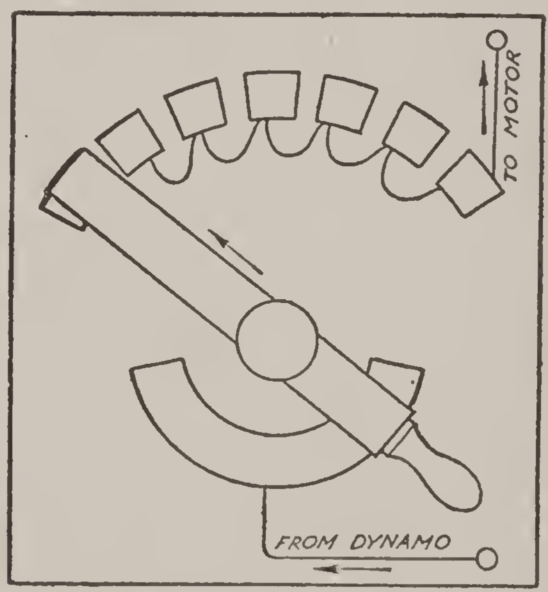


Diagram of the Rheostat

Each of the square stops is connected with a resistance coil underneath and the coils connected in series. On the left is a neutral coil. The switch being moved to the right, it cuts out the coils successively till it reaches the right, when the current passes direct.

made by coiling wire on two cylinders of the same size, one of wood, the other of brass, and so arranged that the current is resisted more and more as the length of wire wound on the wooden cylinder was increased. A longer description is not necessary, since much better instruments have since been devised.

Likewise in 1845, there was another use of the electric current in blasting, when a great cliff was destroyed, by means of the electric fuse. This was at Dover, and three charges were used, 18,500 pounds of powder being *fired at the same moment* by voltaic battery. The advantage of this simultaneous blasting over successive explosions was very great, and is evident. The electric current made it possible and easy, whereas by any other method it would have been most difficult. Professor Wheatstone in England laid a wire across the bed of the River Thames, eight months after Morse's similar experiment in New York harbor, and succeeded in sending current through.

It is interesting to learn that during the period of depression about the Morse telegraph line, Alfred Vail devoted himself to reading Faraday's Researches in the hope of finding a way out of the troubles. By February the decision was made to put the wire on poles instead of underground — a thing that had been done virtually by Weber at Göttingen in 1823, as was mentioned — and during March and April this work went on. By April 12, twelve miles were successfully wired, Vail signalling to Morse at Washington along the line as built. Later in April, an earth circuit was used for part of the line, applying Steinheil's discovery. On May 23, 1844 the line was done as far as the Baltimore depot at Mount Clare.

The year before, 1843, Morse had promised Miss Ellsworth the honor of sending the first message.

Toward the close of the session of Congress, Morse had been in attendance upon the Senate. The last day came, and he left at nine o'clock knowing that about

a hundred other bills would come up before his own. That night he found he had only seventy-five cents beyond the price of his ticket to New York. Next morning, as he was leaving, he was told that a visitor was in the parlor to see him, and when he entered the room he met Miss Annie Ellsworth, daughter of the Commissioner of Patents — one of his warmest friends in Washington. She offered congratulations, to Morse's surprise, and then told him her father had remained to the end of the session, and knew that the bill had been passed March 3, 1843.

"Annie," Professor Morse replied, "the first message from Washington to Baltimore shall be sent from you!" She was the first to give him the good news.

On May 24, the line was finished, Miss Ellsworth dictated the message, "What hath God wrought?" and Morse at 8:45 A. M. sent it successfully to the Baltimore end of the line. This was the beginning of commercial telegraphy by the Morse system.

Meanwhile Vail had begun transmitting simply by hand, making and breaking contacts without the use of transmitting mechanism, and soon made a little spring-key for the purpose — thus making the working of the line simpler. And the complicated recording instrument also was before long to be gradually replaced by a simple "sounder" which the operator reads by hearing. Still, these were but omitting features by experience, and the fact remains that the first telegraph designed upon right principles was built upon the plans and carried through by the efforts of Professor Morse. By this fact he must be judged, rather than by the fate of his apparatus when time had caused it to be improved. As for the Morse

Alphabet, it may be that it was worked into its present form by Vail, as shown by Franklin L. Pope in the *Century Magazine* for April, 1888; but the underlying idea, as a later correspondent showed in a letter to the same magazine may be traced at least as far back as Francis Bacon's secret alphabet, and Vail's work upon it was mainly that of an improver.

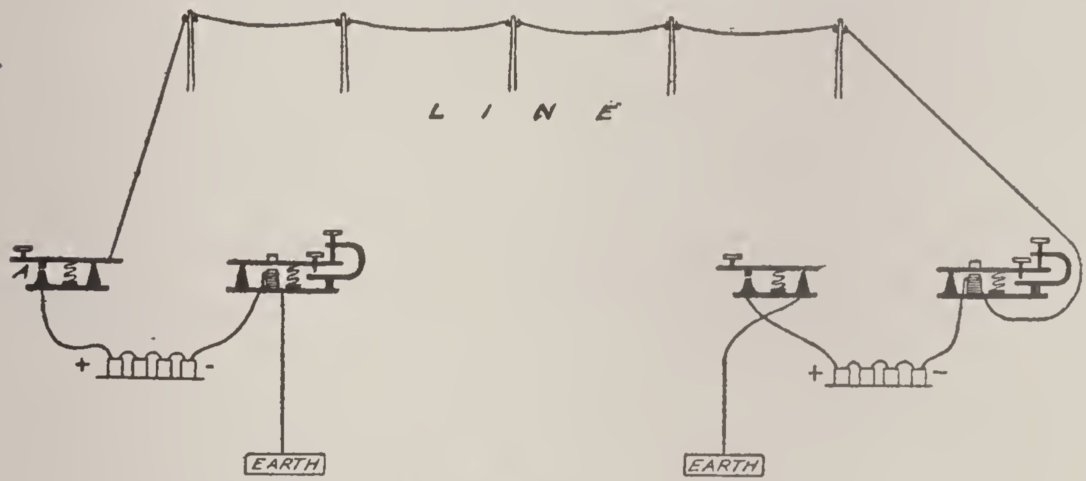


DIAGRAM OF KEY AND SOUNDER

By depressing the lever of the key the circuit is closed at A. This causes the sounder at the other end of the line to be actuated by an electro-magnet, thus repeating the signal, giving a series of clicks, which are read by the operator.

There is no need for weighing too exactly the claims of rival inventors, especially if, as here, they were partners working toward one purpose. A remark by either during their work might be the germ of an invention by the other, and such suggestions might have been exchanged daily without any record being made. Every inventor must be fed upon the ideas of others.

Between 1841 and 1844 two French experimenters, Deleuil and Archereau had been showing various electrical displays in Paris, and are said to have shown the electric arc in a vessel closed against the air to make the carbons last longer. But though the principle was right, there were commercial difficulties that prevented them from making the light available for

public use, since there were no good carbons, and no steady and cheap current to supply large lamps. Besides, there was as yet no way of keeping the carbons just far enough apart to permit the formation of the arc, and when carbon had been burned so as to increase the distance, the circuit was broken and the lights went out. Further inventions were needed to remedy these defects.

The next year, 1845, saw an improvement in the incandescent light. A young American named John W. Starr, of Cincinnati, is declared by the authors of "The Electric Light," Alglave and Boulard, to be probably the inventor of the incandescent carbon light. Incandescent wires had been used, but even platinum, the best for resisting the high temperature, had to be kept at temperatures lower than would give a clear white light, and at these it gave a yellow or red light. Something less fusible was sought, and while, we read in the book quoted, these were "not wanting, most of them could not be reduced to fine wires, and burned readily." Carbon if kept in a vacuum was the desired substance.

Diagram of Starr's Lamp

A—Carbon rod, heated to incandescence by the current.

The lamp made by De Moleyns in 1841 had a device for dropping powdered carbon on its incandescent platinum wire, but the whole lamp was not effective. Starr's lamp inclosed a rod of carbon in a vacuum, or "vacuous space," as Houston terms it, formed in a glass oblong tube. The current was brought in by platinum connections.

Starr was too poor to do much by himself, but was aided by George Peabody the philanthropist. Taking a man named King as a partner, he sailed for England, and there exhibited his lamps. One exhibit was a candelabra of twenty-six lamps to typify the number of the States in the Union at that date. Among the spectators was Faraday, who helped in the experiment, admired the lamps, and predicted success.

Soon after, Starr and King embarked for America, and next day Starr was found dead in his berth. He was only twenty-four years old. King had patented the lamp, describing its main features, and stated that more than one could be used in the same circuit, and that either a battery or magneto-electric machine would operate the lamps.

Except that the method of securing the partial vacuum differed, Starr's lamp has all the main features of the incandescent lights of to-day though in a far inferior form. The current required to raise a thick carbon to incandescence was of course largely wasted, since only its surface could give light. Indeed in a recent article an electrical expert is quoted as declaring of it, "It produced a brilliant light, but was in various aspects unsatisfactory." Nothing ever was done by King, Starr's partner in the enterprise, and his name is connected with the lamp only because the patent was taken out in his name. Professor Houston remarks that this invention "discloses a remarkable knowledge of the subject, considering its early date."

The same year saw the issue to Wheatstone of an English patent for the use of an electro magnet as a field magnet in place of a permanent magnet, in electric machines, thus giving them greatly increased

power, and enabling them to be run by a battery; and Faraday made another "pioneer" discovery of most striking value. He had been experimenting on polarized light, and found that its rays were caused to rotate by a magnet—suggesting at once a connection between electricity and light, and one afterward studied in developing the theories of electric vibration.

We cannot here go into the matter of the polarizing of light beyond the general fact that it is supposed to be caused by a change in the direction of the ether waves causing light, and that the action of the magnet was an indication that both magnetism (and therefore electricity) and light were caused by a motion in the ether. There were also certain studies by Neumann upon the mathematical theory of induction, which the reader may consider only for the purpose of bearing in mind how each new phenomenon in the practical science of electricity was at once made the basis for deep reasoning by scholars, and the announcement of the exact laws governing it. We are far too likely to consider discoveries and inventions as proceeding from a certain vague faculty we name "genius," and it is well to remember Faraday magnetized *thousands* of needles under various conditions in order that he might be sure of some suspected principle of action.

The value of such studies also appears in the fact that whenever the arts have hit upon something new, the men of science are able to foresee how the new thing may be applied; and when the practical men have found a need, the men of science are able to point out how it is to be supplied. Thus Starr's lamp contained a platinum wire fused into its glass bulb, making a way for the current to reach the car-

bon. As a man of science he knew that when glass and platinum are heated they expand at nearly the same rate, and so the expanding of the platinum does not crack the glass. This fact was probably known, and set down in tables of "coefficients of expansion" long before any one had foreseen that the knowledge would be of use in making electric lamps.

Classified, scientific knowledge lies ready to hand, like well kept tools in a systematic work-shop; and no one can foresee that such bits of information will not be precisely what is needed to complete some widely useful appliance.

Each year in electrical history is marked by advance in theory and practice. In 1846, the laws of induction were carefully verified by Professor Weber, the same who worked with Gauss and with him set up the induction telegraph line in Göttingen; and a new practical application of the heating of a platinum wire put into a circuit was made by Crusell of St. Petersburg, who so arranged a loop of platinum wire that it could be drawn close about a vein or a small growth it was desired to cut off in an animal, at the same time that it was heated by the current. This formed an electric surgical cautery, that in the same operation could cut and sear the wound to prevent bleeding, as in removing a part of the tongue, or other organ full of small blood vessels — a most valuable aid to the surgeon in many operations.

The electric light was used in this year upon the operatic stage, representing the sun, in the opera of "La Prophéte." Two Englishmen, Greener and Staite, also at this time patented, perhaps independently, a lamp on the general principle of Starr's —

improving the carbon by purifying it and solidifying it in an acid bath. But this was an improvement not followed up for nearly thirty years — probably because of the cost of the process, and the difficulties of renewing carbons when burned out, as well as the lack of means to furnish a strong and steady current to many lamps.

Every year saw new devices brought out for applying the principles already known, but all were doomed to commercial failure because the time was not yet ripe for them. Dr. John W. Draper, of New York, experimented with an electric light, Farmer with an electric car, in 1847; but neither was the beginning of any practical development that requires us to become acquainted with their mechanism and principles.

In 1848, the Morse telegraphic apparatus was taken to Germany by two Americans, but they could not secure patents, and so had to keep their ways of working secret. Professor Houston tells how these men were able to telegraph clearly over longer circuits than could be covered by the Wheatstone or Steinheil systems, and so greatly surprised the German experts. Their secret lay in the Morse relay — which we have described — and this was kept concealed in a box. They made a line that worked for ninety miles, and much mystified the foreign experts. Steinheil guessed the secret to lie in the "magic box," and when the relay was explained "generously acknowledged to Morse the superiority of the latter's instruments over his own" — to quote Houston's words.

At this time, or a little earlier, was proposed by another inventor, Bain, a telegraph recorder capable of much greater speed than any then in use. This

was his "Chemical Telegraph." It was to use strips of perforated paper to send the message — contact being made whenever a hole came between the key and line—and a strip of chemically treated paper to be discolored by the passage of the current in the receiver. Both strips being run by clockwork, and many of the sending strips being prepared by a number of operators beforehand, great speed of transmission was possible. The paper for receiving could be prepared by soaking it in iodide of potassium ; then the electric action would cause a brown stain wherever it passed. Wheatstone also had an apparatus of the same kind.

But the ingenious reader will see that with the possibility of controlling motion and so producing a contact at the end of a telegraph line, *any* form of mechanism could be set in motion and stopped at will. The period of wonder was at an end, and the period of ingenuity had begun ; or, we may say, discovery had been completed, and the principles established. The rest was the work of the mechanician.

CHAPTER XIV

THE DAYS OF TELEGRAPHY

STILL a new idea was in the telegraph of Bakewell — the *fac-simile* telegraph. This was invented from 1848 to 1850. To understand it we must imagine two metal cylinders to be turned at the same rate in two stations distant from one another, and kept accurately timed, so that their motion is exactly the same. Around each is a fine spiral groove filling the surface closely from end to end. One cylinder, A, has drawn on it in varnish (a non-conductor) a design or drawing or writing. The other, B, has a piece of chemically prepared paper. Now, let a point be allowed to travel in the grove of A, and another in the grove of B, at the same rate. The first point is connected with the battery, and allows a current to pass whenever it touches its cylinder A. The other point rests on the chemical paper (a conductor), and causes a stain whenever the current comes from A. The design in varnish will then break contact whenever the point A crosses a varnish line, and will therefore fail to send a current. The paper at B will show a stain whenever a current has passed or *white* where it has failed to pass, and thus the chemical paper is stained except in the lines of the original design, as drawn upon cylinder A. These will be reproduced in white, on the stained ground.

The timing of the cylinders can be done either by clockwork and pendulum, regulated by electric im-

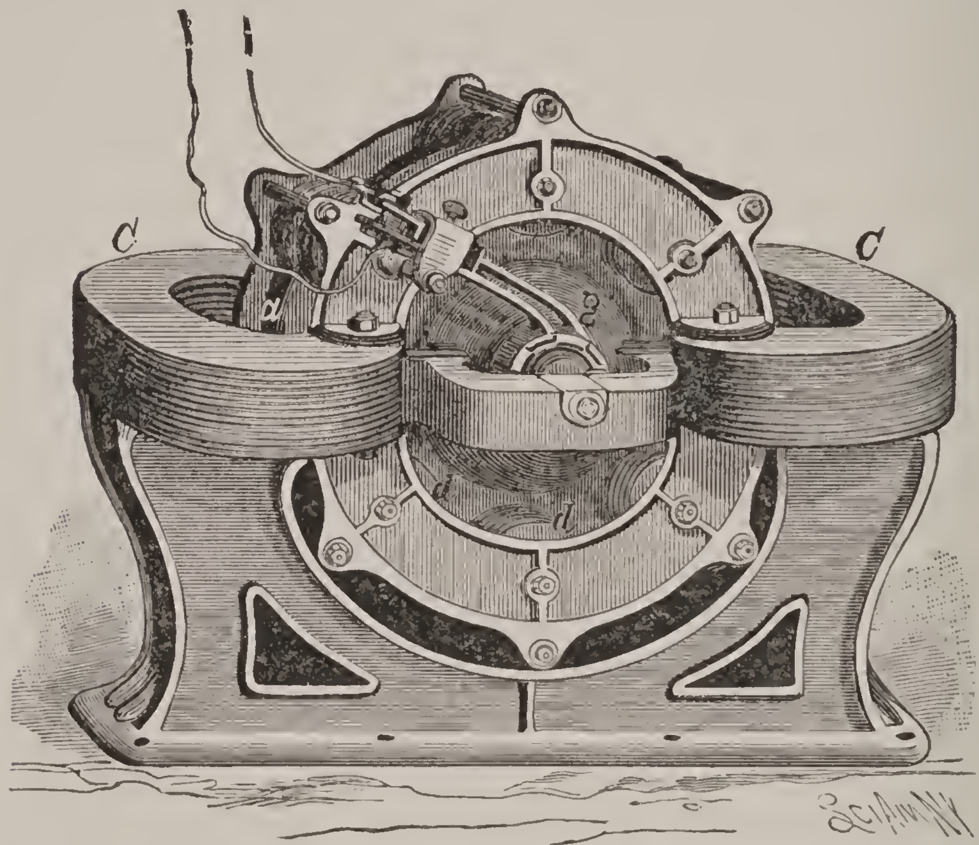
pulses, or both regulated and driven by them. A printing-telegraph, as suggested by Vail in 1837, was in a greatly improved form patented by House in 1848; but these ideas came to a better form in the Hughes Printing Telegraph seven years later, which will be spoken of in its place.

Since 1839 there had been a number of attempts to insulate wires so thoroughly that they might be used under water, and retain their insulation for a reasonable time. At first, cotton or hemp wrapping coated with asphalt was tried, but the right material was not found until 1848, when a gutta-percha coating was used. Though a wire so coated and laid between New York and Jersey City soon failed for lack of a protective covering it was the forerunner of the successful submarine cables.

But a principle of the very greatest value to electrical development dates from this same year. This was an improvement in dynamos. The first suggestion of it came in 1845 from Jacob Brett, who spoke of using the current set up in the armature to give more strength to the permanent field magnets; but the actual machine accomplishing this was patented in England by a Dane, Soren Hjorth of Copenhagen, and may have been independently discovered by him.

He used permanent magnets to excite his armature, and then taking a current from the armature sent it around smaller electro-magnets that also acted on the armature, so increasing the strength of the field currents, and thereby obtaining better results. This, it will be seen, was the introduction of an unnecessary link, since the same current that excited the electro-magnets might have been used to excite field mag-

nets originally. The doubling of the field magnets was the introduction of more resistance; but this was not to be perceived for some time, and Hjorth at least had in his magneto-electric machine the true principle of modern dynamos. His invention was probably made not very long before 1855, as his patent was dated in that year. The idea of strengthening mag-



HJORTH'S DYNAMO
A—Armature. C—Permanent magnets. D—Field magnets. G—Commutator.

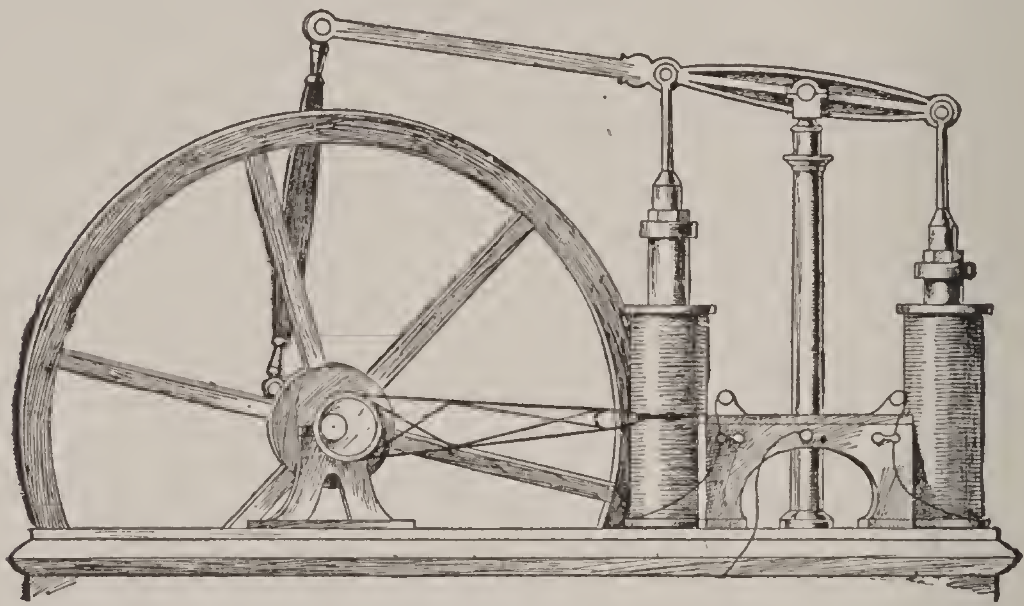
netism by using the armature current, however, was not yet fully recognized, as we may know from the next development of the magneto-electric machine. Nollet, Professor of Physics in the Military School at Brussels, in 1849 improved the Clarke machine — the one that revolved electro-magnets before the sides of the permanent magnet poles — but it was by multiplying the number of permanent and electro-magnets rather than by using any new principle.

This new machine was meant to decompose water into its gases, and then an illuminating gas was to be manufactured. In other words, this machine was a device meant to produce gas for gas-lighting, and it failed for the simple reason that it cost less to make gas from coal. So this machine was put aside for a while, to be revived later when the possibility of practical electric lighting made its power available.

The middle of the nineteenth century, as will be seen, had thus been reached with the science of electricity well founded. The theories had been well studied; a great number of machines invented that failed more often because of trade conditions than for scientific reasons; and the work of specialists was well begun. Yet everything was in its infancy. The telegraph was established as an enterprise, but chiefly for short distances on land. The use of electricity as a motive power was too expensive and too uncertain to compete with steam power. The electric light was even less advanced, being little more than a wonder for short exhibitions or for use in a few limited fields.

All the actual outdoor development, the real trade and business use was to be brought about in the lifetime of men still living — such as William Thomson, Lord Kelvin. Thus the first submarine cable, between Dover and Calais, was in 1850 only a single copper wire in gutta-percha, and failed after working for a single day; but in 1851, the next year the same cable was relaid as an *armored* cable and was successful. The core of conducting wires was insulated and then outside was an armor of wire closely wound to protect the insulation from injury. From about the same time dates the perfected Ruhmkorff coil, and also the

electric locomotive of Page and Vail, a really practical invention that ran from Washington to Bladensburg, for one mile at the rate of nineteen miles an hour; though its motor is now chiefly



Page's Electric Motor

Two soft iron cores were drawn into the coils alternately, the current being shifted by a commutator from one to the other, this producing a reciprocating movement of the lever. This machine was applied to the first electric locomotive in America.

notable for being among the predecessors of better types.

All these early motors derived their power from voltaic batteries, and zinc cost twenty times as much as coal while it produced only an eighth of the work for the same weight. In small apparatus, electricity was proving most valuable. The electric bell, for example, invented — so far as the "trembling" contact is concerned, by Miraud, had come very early into general household use. The old style of wire and bell-pull was a clumsy and uncertain contrivance, as all who remember it will willingly bear witness, and the mere fact that the electric wire was not moved in ringing the bell, made it immensely bet-

ter. The little Miraud "Trembler," was only the contact-breaker seen in the Ruhmkorff coil. From 1852 to 1856 inclusive the chief steps in development were in improving the telegraph and the electric light. The application of the telegraph to a system for giving the alarm of fire was first made by two Boston inventors, Channing and Farmer. It was no more than an adaptation of the telegraph to a special use, being a number of circuits connected with a central station. In each circuit, in an iron box was a device for sending to the central station a signal that would indicate where the signal came from. This signalling can be done mechanically, a lever being pulled down against a spring; as the spring returns the lever makes electric contacts with points in its path so as to ring a bell in the station — and as the points are differently arranged, the ringing of the bell shows the number of the box from which the message comes. The same system is used to-day in the box of the district messenger service.

But an invention, as distinguished from an application, was made in the telegraph during 1852–3–4–5 by doubling the capacity of the lines. The first suggestion came in the first year mentioned, 1852, from Moses Farmer, the first practical application of the principle being made by Gintl in Amsterdam in 1853 and 1854, and improvements in the apparatus were due to Preece of England, and Frischen and Siemens and Halske of Germany during 1855. The practical duplex telegraphy, however, was not applied to the working lines for several years later, when perfected after 1870. The general principle of the duplex apparatus may be here stated, since this principle was

discovered at this time, and only failed to work because of an oversight on the part of the inventors — the omission to allow for the electric capacity of the line and apparatus — that is, the loss of electricity in its working.

Suppose we wish to "duplex" a line. That means to arrange it so that a signal sent from one station A, to another station B, shall affect the receiver at B, and yet leave the A receiver unaffected; while a signal sent from B shall affect the A receiver, and not its own. This requires some apparatus, for in a single line a signal sent from either end would act on the whole line, including both receivers unless one or the other was shut off. But we want to use both receivers, independently, at the same time on a single line.

There are two ways of doing this, both by means of inserting a relay in the line. One way is to insert what is known as the Stearns or neutral relay. This is a double wound electro-magnet around which the main line wire is wound after being divided into two branches. One branch is wound from right to left, the other from left to right around a bar of the magnet. Then half the line is connected to the earth and the other half goes to the other station.

There are now two things to accomplish. First to send messages to the distant station without affecting the home receiver (or "sounder"). Second, to receive messages without affecting your own use of the line. We will examine each separately.

If you put down your own telegraph-key, closing, or making the circuit, the current is formed. It passes up to the branch Y and then (by Ohm's law, the re-

sistance being made equal) the currents in each branch are equal, and one-half goes by the left branch of the Y around one-half of the electro-magnet, then down into the earth, and is there lost. The other goes, *in the reverse direction* around the other half of the electro-magnet, and then out by the main line to the other station. But the two opposite currents around the electro-magnet neutralize each other, so that the electro-magnet does not act at all on its armature. So far as that current is concerned, the magnet is left unaffected, whether current is turned on or shut off by your key, and yet half of your current is sent along the main line whenever your key makes contact.

Therefore you can send messages without affecting your own "neutral relay," and as this relay must act to affect your sounder, your own current does not move your own sounder. And likewise at the other end of the line the other operator's key will not affect his own sounder. But remember that this is done by making the two branches of the Y offer *equal resistance*, so the current will divide equally on the two sides of the relay magnet.

The next object is to arrange that the current along the line will affect the sounder at the distant station. Let us follow it. The current arrives first at a coil around a half of the electro-magnet winding of the other relay, making it exert magnetism. Then it goes along the other branch of the Y at the far station to the junction of the branches. Here it meets two paths. One is up the other branch, and around the other half of the electro magnet. This part of the current goes *in the same direction* around the magnet as in the first coil — and so the two coils act together, and at-

tract the armature. When the armature is attracted, it closes a circuit connecting a new battery with the sounder, and the sounder gives a signal. Thus a current *from* the main line inward, moves the sounder, while a current outward along the line does not move the sounder of the office from which it is sent.

But we must still account for the *rest* of the current that came from the farther office and did not go up the second branch of the Y. This will fill the wire down to the key. The key will be either open or closed. If open, the current will find a broken circuit. If closed it will be met by the closed circuit sending a current to meet it — a current as yet not divided by the Y, and therefore of twice its strength. Either way, this remainder of incoming current will not act on the relay, to interfere with its signals.

This explanation of the duplex system is of course meant to show only its main principle. The adjusting of resistances, and the use of "condensers" to make provision for surplus current, do not affect the main principle and must be explained by technical books.

All the reader needs to remember is that duplex telegraphy in its first and simplest form was accomplished by: first, dividing the outgoing current so that its halves neutralized each other in opposite winding as to the home sounder; and, second, allowing the incoming current to act as a whole, since it went in the *same direction* through both coils of the distant sounder. Of course it makes no difference, in principle, whether the current acts directly on a sounder, or simply opens and closes a circuit that brings the sounder into action. And likewise of the key. This too may either close the circuit of the main line, or

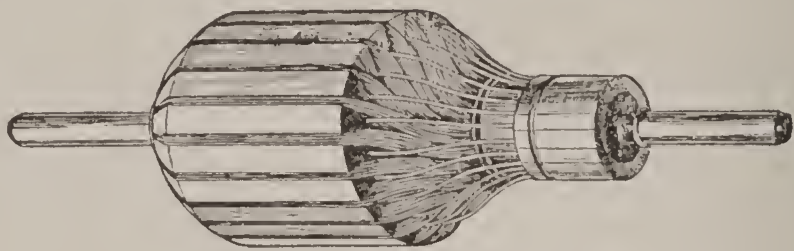
may close a circuit that closes a switch that makes a circuit on the main line.

Just as in arithmetic the most complicated calculations come down to the four rules — add, subtract, multiply, divide; so, in electric apparatus, the most complicated machines come down to the same simple rules, adding current, by making a weak one bring a strong one into action (by the relay); subtracting, by turning the current into the earth or into a high resistance or making it do work; multiplying, by changing the tension from low to high (by the induction coil, the Leyden jar, and the condenser); dividing, by lowering tension, or by separating one heavy current into a number of branches.

Going back now to 1850 we shall find another development in the motor, due to Professor G. C. Page of the Smithsonian Institution, Washington. This was a walking-beam engine, driving a fly-wheel; the beam was moved by two coils that attracted alternately two core-rods of iron. Attached to the fly-wheel was an eccentric rod that moved a commutator, and at the right times transferred the current from one coil to the other. This motor, run by 100 voltaic cells, was the motor-power that ran the engine before mentioned from Washington to Bladensburg at a good speed. But the jolting interfered with the batteries.

In 1854 was invented the Siemens armature, first designed for use in connection with a telegraph apparatus; but it afterward came to be a most important step in the motors and dynamos, of early days, being adopted in the first successful forms. Siemens' armature was made by cutting square edged open channels out of a long iron cylinder, and then winding

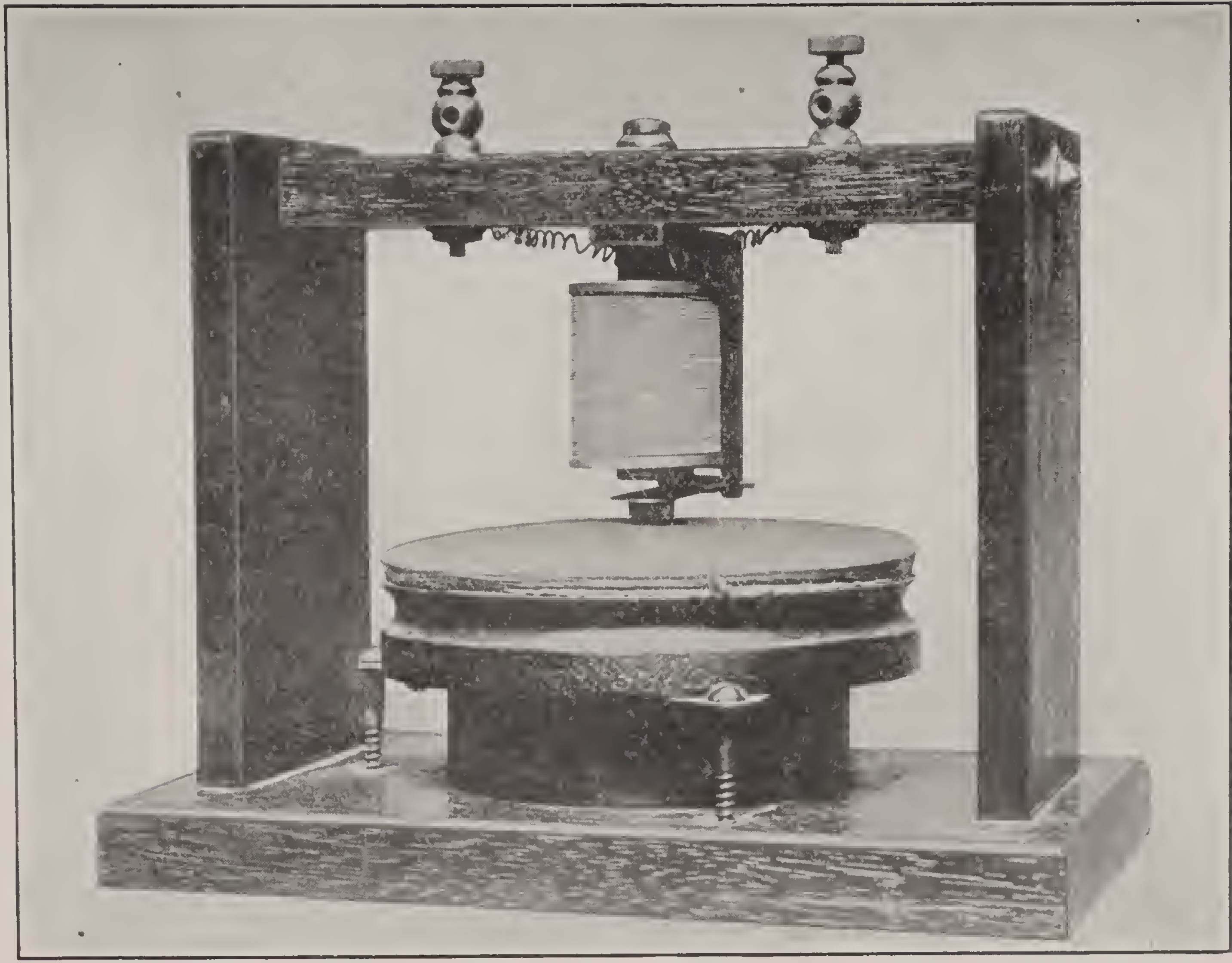
the wire lengthwise in the channels. This form of armature was long and narrow, and allowed many electric magnets to be put closely along its sides, an evident advantage in compactness. The same year saw the first suggestion of the really practicable form of submarine cable — Sir William Thomson having suggested the stranded, or rope-wound form. In



THE SIEMENS ARMATURE

1854, also, came the publication of a article in *L'Illustration* by Charles Bourseul, a Frenchman, which is declared by a recent writer to be "strongly suggestive of the speaking telephone." But though Bourseul spoke of a flexible plate that would vibrate, and open and close a circuit, thus causing a distant plate to be attracted and released by an electro magnet, there was no description to show that this crude idea was put into practice with the many modifications necessary to make it repeat sounds like those that moved the first plate. It is no more than the first crude suggestion of the invention afterward made by Reis in 1860.

In 1855 came a beautiful simplifying of the Daniell cell. Instead of separating the two chemical solutions — a weak solution of sulphuric acid and copper sulphate — by means of a porous cell, an English inventor, named Varley, knowing that the copper sulphate was heavier in weight than the weak solution of



THE FIRST TELEPHONE
(*See also page* 206)

sulphuric acid, put it into the glass jar, and then pouring in the weak solution of sulphuric acid allowed it to float upon the heavier liquid, as oil will float on water or vinegar. Then the copper element was put into the bottom of the jar, with crystals of copper sulphate, while the zinc was supported above, in the sulphuric acid solution, by being hooked on or rested on supports across the top of the jar. Thus the principle of the Daniell cell was preserved, and the different elements and acids separated by their own differing weight and position. This was the first "Gravity

THE GRAVITY CELL

Cell" — a modification being in general use to-day in telegraph offices. Zinc sulphate and copper sulphate are the acids, zinc and copper the electrodes or elements. While in action, the cell will keep its liquid solutions separate, but if not producing current, they tend to become mixed together by "diffusion," — a tendency of light and heavy liquids to mingle.

CHAPTER XV

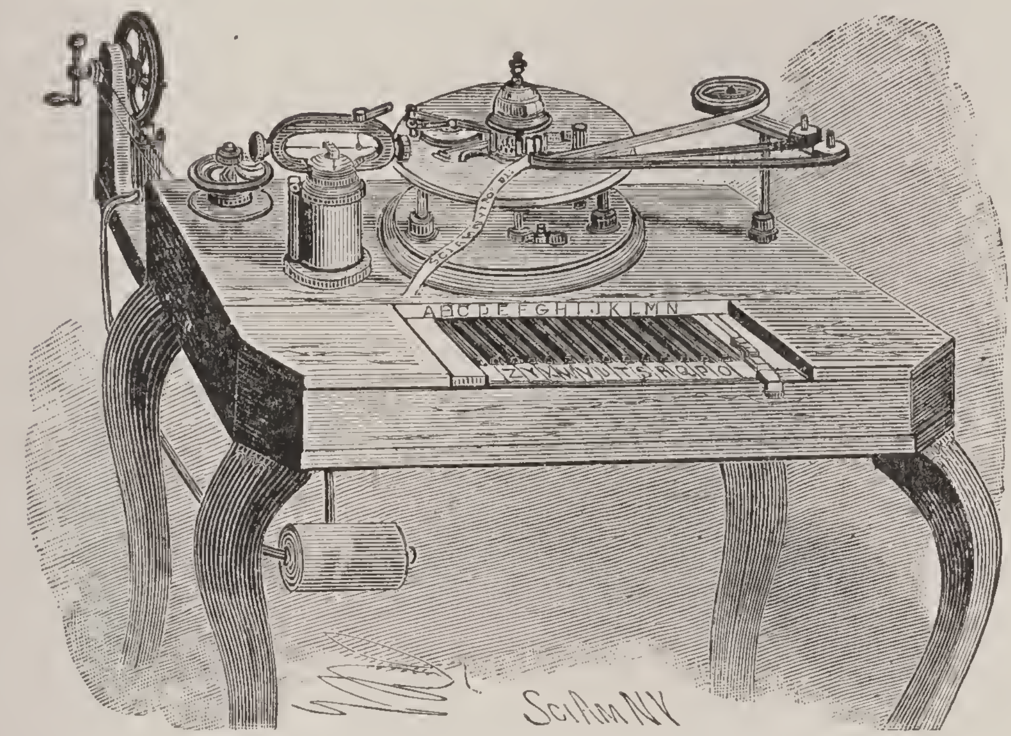
CABLE, STORAGE BATTERY, AND MOTOR

In this same year, 1855, there were further attempts to popularize the electric light in Paris and Lyons. It will be remembered that when the electric arc is formed between two carbons, as they burn away the space between becomes too wide for the current to pass, and the lights go out. Two Frenchmen of Lyons, Lacassagne and Thiers, patented a means for raising the lower carbon as it burned away, and gave exhibitions of which enthusiastic accounts were printed. But in spite of the enthusiasm, and in spite also of the clever mechanism invented by these men and others at about the same time, the carbon-arc light could not be made a commercial success at the time, though it found some use under conditions where a brilliant light was desired, and expense as well as perfect regularity and equality of lighting were unimportant as in theatrical shows, in lighthouses, and in the magical lantern.

There is no space to describe forms that have been long discarded, as the arc lamp is still in general use, and improved methods of regulating the supply of current and length of arc will be explained. More important is it to describe the Hughes Printing Telegraph, if only to show a machine that is an excellent type of the whole class. We have already spoken generally of Wheatstone's. Hughes's machine requires only one touch to send a letter, instead of three

or four on the average, as in the Morse instrument. The message is also printed in both sending and receiving office at the same time — thus checking its accuracy.

The sender is a keyboard like a piano or typewriter keyboard. The receiving instrument is a very compli-



THE HUGHES PRINTING TELEGRAPH

cated apparatus run by clockwork and a weight. This is arranged so as to keep time with the other receiver. Then, whenever a key is pushed down on the sender, it pushes a peg through a hole in a disk revolving horizontally, and thus causes a current to pass just at the right moment to press a strip of paper against a type-wheel that turns at the same rate as the horizontal disk, and prints the chosen letter.

To describe this complicated apparatus in full is unnecessary because the ingenuity of the invention is almost wholly mechanical rather than electrical. The

electrical features presented little that was new, and though the apparatus came into extended use in America and abroad, and served a good purpose, it did not aid directly in the progress of electrical science.

The year 1856 marked an era in the telegraph business, being the date of the incorporation of the great Western Union Telegraph Company, which was the title under which several companies consolidated. In 1851 over fifty companies were in existence, using mainly the Morse system, but also using Bain's chemical telegraph, and a form of printing-telegraph known as House's. The parent company of the Western Union was a company formed in Rochester, New York, with the purpose of extending lines westward, and it had only limited success; but its rival companies were by 1854 in even worse shape, their resources being exhausted and their lines nearly in ruins. There was but one successful company, which operated between Pittsburg and St. Louis on the line of commerce from the Southern and Western States to the eastern cities.

The Rochester company succeeded in acquiring cheaply the assets of most of its rivals, and in the course of a few years order and enterprise took the place of neglect and indifference. New and better methods were adopted, the company was incorporated by the new name, and the Western Union came into existence by act of the New York Legislature on April 4, 1856 — just a half century ago.

During 1857, the Western Union was busy in putting itself into a practicable shape, and meanwhile further steps had been taken in the use of submarine

cables. There had been a number laid and used for limited distances, and for a short time, and the art of insulating them had so far progressed that in 1849 more than two miles of wire were coated in twenty-four hours. The Dover and Calais cable had been proved practicable, being six years old, and the theories of submarine conductors, thoroughly discussed by Faraday and Thomson in 1854, were fairly understood, so that the difficulties sure to occur in working long cable lines were foreseen, and could be somewhat provided against.

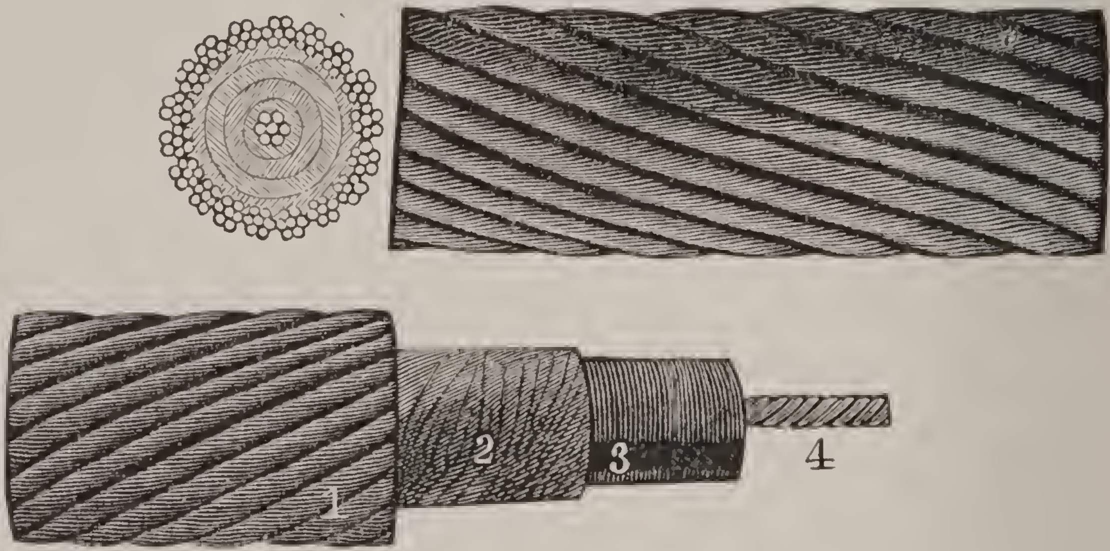
Among these difficulties one of the most important was the fact that the insulated wire or wires within their coating had — like a Leyden jar — a great capacity for electricity. The wet outer surface was like the outside of a Leyden jar in contact with "earth"; and so of a charge of electricity sent in at one end, part would remain in the cable, held by induction (as in the Leyden jar) and another part of the charge would escape from the line since no *absolute insulator* exists — all leak somewhat. All this had been worked out mathematically by Thomson — and rules were ready for the engineers' guidance.

Before the end of 1855, experiments had proved that signals could be sent through more than 2,000 miles, and a survey of the Atlantic bed between the westernmost part of Ireland and Newfoundland had shown a depth of 1,700 to 2,300 fathoms with a gently undulating plateau most of the way. Shells of the most fragile nature were brought up uninjured from the depths, showing no disturbance existed.

A cable was made and in August, 1857, there were laid 335 miles successfully — and then the cable broke.

The fleet had started from Valentia on the Irish coast and consisted of eight vessels, four American and four English, and had been out four days.

In 1858, a better way of stowing the heavy cable — ten tons to the mile, was its weight — and better



ORIGINAL ATLANTIC CABLE

1. Protective coating of twisted wire. 2. Gutta Percha. 3. Wrapping of thread, soaked in pitch and tallow. 4. Conducting core of seven copper wires.

devices for laying it were adopted and June 10, a second start was made, the vessels being the British frigate *Agamemnon* and the American frigate *Niagara*, each with a tender. They went to mid-ocean, and then separated after splicing the two halves of the cable. The cable broke three times, at five miles, eighty miles and 300 miles — and then the expedition was abandoned until the next month. Again a start was made July 17, 1858, and once more the halves were spliced and the vessels each turned homeward. On August 5, Mr. Cyrus W. Field — "to whose energy and public spirit the enterprise was largely due," declares the author of "Progress of Invention in the Nineteenth Century" — telegraphed from Trinity

Bay, Newfoundland, that the cable was laid, and connection made between that place and Valentia in Ireland, a distance of 2,134 miles.

Messages were exchanged between Queen Victoria and President Buchanan, conveying mutual congratulations, but so great was public skepticism that it was by many thought these were spurious, and only when telegraphic news from England had been confirmed by letters brought in vessels was the public convinced that the cable worked.

There were in the cable 2,022 miles of wire, and the problems presented to the engineers and operators were of the most puzzling description, and of complete novelty in detail. The cable was much thicker at each shore end, tapered to less than an inch in diameter in the deep-sea portion, and was capable of standing a strain of over three tons. The induced currents were most troublesome, and had to be met by special inventions made as the need for them developed by experiment. All these difficulties were successfully coped with, and the cable transmitted its messages for about a month without sign of weakness. But though the cable lasted long enough to send a number of important messages, 366 in all — one preventing the unnecessary sailing of two Canadian regiments, saving $250,000, and another announcing the safe arrival of the steamer *Europa* after a collision, saving weeks or months of suspense — it lasted hardly more than a month, and failed on the day set for Mr. Cyrus Field's New York celebration.

This cable of 1858 had cost a little over $1,250,000. After its failure came a time of delay and renewed study of the subject and its difficulties that lasted un-

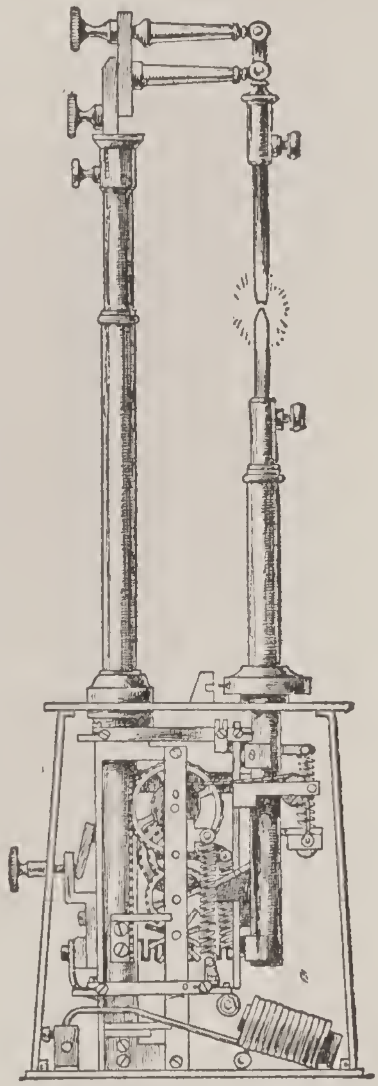
til 1865, about seven years — a delay no doubt extended by the war in America.

The duplex system of telegraphy had been in 1858 greatly improved by the inventor Stearns of Boston, and abroad the electric light was used in the South Foreland Lighthouse — being supplied with current by two magneto-electric machines run by a steam engine, and employing the carbon arc light. This was probably the first use of electricity in lighthouse work.

In 1859 occurred the first use of the electric light for household lighting. To accomplish this it was necessary to subdivide the current delivered from the main, and this was done by Moses Farmer in his own home at Salem, Massachusetts. Two years before it was announced in the French Academy of Sciences that the problem of subdividing the current had been accomplished by De Changy, who lighted twelve lamps, containing incandescent spirals of platinum, by the use of twelve Bunsen cells; but Professor Houston says the lamp was not much used. A similar lamp was patented in the United States in 1858 by Samuel Gardiner and Levi Blossom of New York. All of which shows steady work on the problem of electric lighting, though successful and permanent lighting had to await the general use of the dynamo instead of the voltaic cells for supplying the right sort of current.

A lamp much used in later lighthouse service was that of Serrin, in which the two carbons were connected with clockwork run by the weight of the upper carbon and its holder. This, by means of a chain and pulley raised the lower carbon to meet the upper. But this action was controlled by the current passing

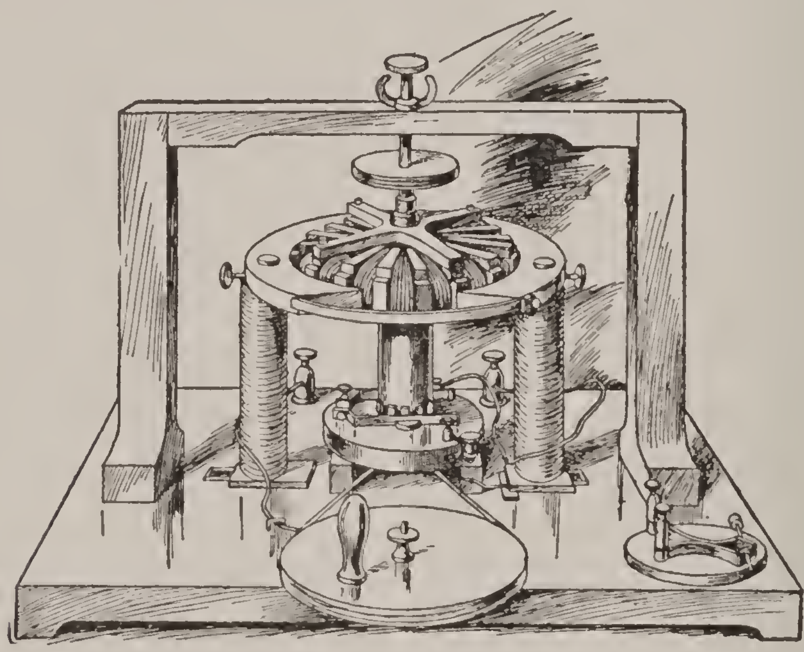
around an electro-magnet. A rather complicated mechanism makes the carbons come nearer together whenever they burn enough to increase the resistance to the current and so weaken the action of the magnet. There is also a device to insure that the arc shall always be in the same place, so as to remain in the focus of the lenses that permit the rays to go out. The apparatus came into extensive use, and has "contributed largely to the success of electric lighting," say Alglave and Boulard in *The Electric Light.* But its value depended upon improvements in mechanism mainly.



Serrin's Automatic Regulator (1859)

With 1860 began a new era in applications of electricity in dynamos and motors, and it is notable, says Elihu Thomson, for two advances of great value and importance. Up to that year electric machines yielded currents that alternated rapidly, or if these were made continuous they fluctuated in strength. The steady current like that of the battery could not be long secured. But Dr. Pacinotti of Florence, Italy, in 1860 described a machine for yielding true continuous currents. The inventor was only a young student at the time, and subsequently, becoming assistant in the Astronomical Observatory, turned his attention to other sciences. Pacinotti's machine consisted of two

electro magnets standing upright, each ending in a circular segment so as to inclose *most of a circle.* Within their poles was a ring armature with teeth projecting from a centre, and this ring armature was set on an axis as a top is — being free to spin about within the semicircular poles. Between the teeth of



PACINOTTI'S MACHINE (1860)

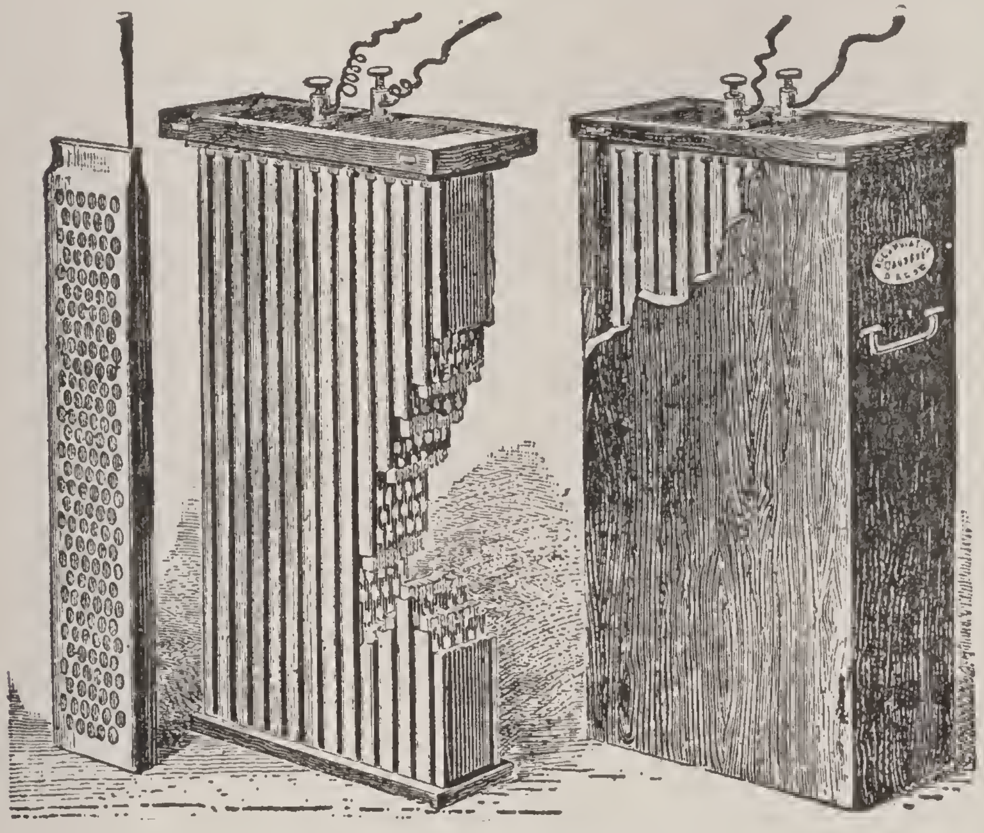
the armature are coils of wire all wound the same way. The ends of these coils are fastened to bits of copper set into a wooden cylinder on the axis of the armature. Against these bits of copper a strip of copper is pressed successively as the armature turns. The current enters the coils of the electro-magnet, and also the coils of the armature one by one. Magnetism is set up in the magnet, and also in the iron armature, and the machine revolves.

But Pacinotti, in describing the machine, shows that if it be revolved by mechanical power, the machine will generate electricity.

Even this machine, however, had its predecessors,

for the American inventor Page, in 1852, and a Dutch inventor, Elias, in 1842 had designed motors on the general principle of modern machines.

The main importance of the Pacinotti machine is the fact that the coils of the armature are all wound in the same direction and all connected together in a method known at a later date by the name of its improver Gramme. The action of this armature will be explained when the Gramme dynamo is described.



PLANTÉ STORAGE BATTERY

The storage of electricity, so-called, dates from 1860, when a Frenchman, Gaston Planté invented his storage battery. The general principle on which it was based was recognized first about 1801 by another French investigator, Gautherot, who discovered that wires used in decomposing salted water would retain

the power of giving out current for a time after they were disconnected. Two years later an investigator named Ritter made a "secondary battery" from plates of copper separated by cloth dampened with salt solution, and found it for some time retained, after being acted on by a voltaic battery, the power to yield a reversed current. De la Rive also found evidences of similar possibilities, and secondary currents were studied by Faraday, Grove, Wheatstone, and other theorists and experimenters. But Planté devoted his attention especially to finding what metals and chemicals would act most energetically, and was able to devise an excellent secondary cell.

Planté increased the action and made it more lasting by winding two sheets of lead spirally about one another, with studs or rubber strips between to keep them separated. These sheets were then put into a glass jar containing diluted sulphuric acid. In order to charge these secondary batteries, they were connected for a long time with voltaic cells, and the current allowed to pass through the secondary battery in one direction. Then the direction of the current was changed, and allowed to pass for an equal time oppositely. The effect of the current is to change the condition of the lead plates. By electrolysis, one plate — that connected with the anode — becomes covered with a layer of peroxide of lead, while the other — connected with the kathode—changed into a spongy condition. When the primary cells are disconnected, the secondary cells are left in such a condition that they are like a new voltaic cell. The peroxide of lead is decomposed again, the spongy lead receiving some of its oxygen, and electric action being set up by the

returning of the secondary cell to its original condition, where both plates are coated with a monoxide of lead.

The reason for reversing the action of the current in charging is to improve the secondary effects, perhaps by breaking up the surfaces of the lead plates.

It will be seen that this is in no sense a storage of electricity, and the new cell is better called a secondary cell, as the voltaic cell acts on a new cell so as to turn it into a voltaic cell. It is simply a reversible secondary cell. After these Planté cells are charged they may be connected in series or in multiple as if they were voltaic cells. If it be remembered that the resistance offered by the cells of a battery is equal to only that of *one* cell divided by the number of cells when connected in multiple (all zinc to all zinc + all carbon to all carbon) the reader will see that a large number of Planté cells should be thus connected in charging them so as to reduce resistance. After being charged, they can be connected in series, and will give a current of much higher electro-motive force or tension.

Sometimes this joining in multiple and then in series is done by means of a long commutator rod. Turned one way, it connects by means of a strip on each side all the zincs, and all the carbons; which, as the two strips are connected, joins the cells in multiple or parallel. If the commutator rod be now revolved, a set of short bars running through it connect zinc to carbon all through, joining the cells in series. Planté explains that his battery distributed chemical action over many secondary cells, for a longer period, so that the same action (or its reversing) could be used for a

shorter time with more effect. The development of the storage battery (if it must be so called) was slow during its first twenty years of life, and then began a rapid expansion of its uses.

CHAPTER XVI

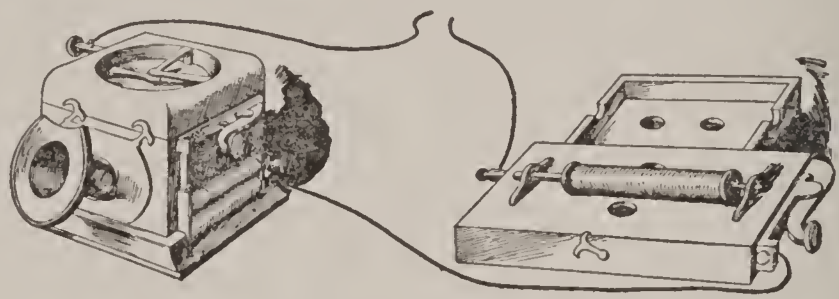
THE ELECTRICAL FIELD WIDENS

To this year 1860 that saw the beginning of right principles in the armature of dynamos, and the first effective storage battery, belongs also the real germ of the telephone and a great part of the work that spanned the American continent with the telegraph. The first telephone was literally that—"far sounder." Of its precursors are usually mentioned the "magic lyre" of Wheatstone, but without good reason, for Wheatstone's apparatus was not electrical, being only a rod of wood connecting two sounding boards of two musical instruments. This only showed that sound vibrations would travel through a connecting material, a fact well known, and illustrated by the child's toy known as the "lovers' telephone"—two disks connected by a taut string. In 1837, Dr. Page of Salem noted and mentioned that musical notes were given when the circuit of an electro magnet was made or broken, and also when an armature of a motor rapidly revolved in front of the poles. Next came Bourseul's article in the French journal, *L'Illustration*, already mentioned, in 1854.

But telephony was first spoken of by Reis in a lecture before a scientific society of Frankfort in 1861. Johann Philipp Reis was a school-teacher in Friedrichsdorf, Germany. He described an apparatus in which a membrane moved by sound vibrations was made to open and close an electric circuit. The cur-

rent was created and shut off in a wire leading to and acting on a distant electro magnet. The making and breaking of the circuit caused the magnet to give out sound of a pitch varying with the movement of the membrane.

Speech could not, according to Reis himself, be thus reproduced, the consonantal sounds being fairly given



THE REIS TELEPHONE
Transmitter and receiver.

but not the vowel elements of words. His idea of making and breaking the circuit, as will be seen, was not enough to reproduce more than the number of vibrations — their quality was largely lost. Yet, accidentally, words and notes were now and then reproduced with clearness; but Reis did not discover how to make these accidental effects the usual action of the apparatus — which was essential in order that it should transmit the human voice and musical compositions.

It may be admitted as Silvanus P. Thompson asserts (quoted by Professor Houston) that Reis's telephone was "intended to transmit speech, in his hands and that of his contemporaries *did* transmit speech, and will still transmit speech." But the principle by which it acted was not understood, or it would have been improved by the surprisingly simple modification needed. Reis's transmitter was a membrane that at "each sound-wave effects an *opening and a closing* of

the circuit." The receiver was a coil of wire through which ran a knitting needle resting on two bridges of wood on a sounding box. This "emitted a tone whose pitch corresponds to the number of vibrations." The words are Reis's own. His receiver, as will be seen, had no true diaphragm, and I think the reader will see that the idea in his mind was entirely different from that of the perfected telephone, so far as the receiver is concerned. But the credit for the first step — the transmission of sound by changing it to mechanical motion, and repeating this motion by electric transmission to a distance is certainly his. There has been much controversy as to how perfectly his telephone transmitted speech, but it seems fair to say that the making of the telephone into a practical instrument required several features of which Reis's apparatus had no trace.

The transcontinental telegraph line had been demanded for several years to connect the systems already established on the Atlantic and Pacific coasts. Objectors urged that the Indians would take the wires and the bison herds would push down the posts. It was thought also that the building and maintenance of the line would be expensive beyond all reason. Aid was asked from Congress, and only $40,000 a year for ten years was obtained. The other telegraph companies believed this inadequate, but the Western Union bid for the contract and secured it — being the only bidder.

Ox-teams were hired in great numbers, Brigham Young contracted to furnish poles and laborers, and an alliance was made with companies on the Pacific coast.

March 15, 1861, the line was finished — requiring a little over four months — and the greatness of the Western Union was begun.

One more notable advance is credited to that year — the beginning of a system of electric units. Mr. Latimer Clark suggested that the unit of resistance in electric conductors should be named after Ohm, the author of Ohm's Law of Resistance. Professors Gauss and Weber had published many papers upon the theory of electricity and its measurement, but no short words for the various quantities and qualities had been in wide use. The British Association therefore appointed a committee that entered upon its labors of fixing and naming the electric standard units. This work was not, however, finally completed until 1869, though progressing and reported at intervals.

The chief electrical events of 1862 were the general adoption of arc-lighting for French lighthouses, and the installing of a great arc-light at Dungeness lighthouse in England; and also the beginning of a new form of electric lamp — again the application of an old principle. This was a vapor lamp that sought to make use of glowing tubes, exhausted almost to a vacuum, through which the current was passed, causing glowing lights of varying colors. Though patented, it does not seem to have come to practical use, any more than did the mercury-vapor lights studied by Hawksbee in 1705, or the later investigations of Cavendish and Davy into similar effects when electricity was passed through the space left by allowing mercury to fall in a closed glass tube, producing the Torricellian vacuum, — that at the top of a thermometer or barometer tube. Yet all of these observations were the

hints of later inventions, that came to fruition when followed up.

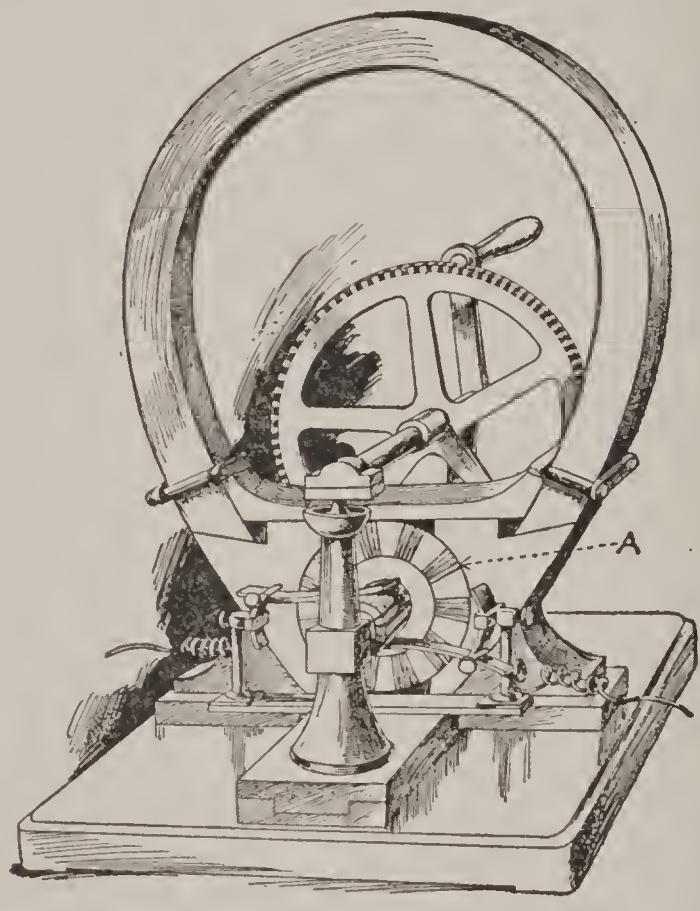
In 1863, the chief work recorded is that of the British Association Committee on naming the electrical units; in other words, carrying out the suggestions of Gauss and Weber who were the first to recognize the great advantage of standards for electrical units, alike in theory and in practice. But an account of what units were chosen, and their meaning should be given only after their general adoption.

The next year came the suggestion from a French engineer, Cazal, that the power of waterfalls might be used to operate railways if it were transmitted by electricity to the desired location. This idea, as we know, was good, but to carry it out required a number of improvements in the apparatus then known. And the same year brought at least one of these — an improved motor embodying a most important principle — the Gramme motor.

The improvement consisted in the arrangement of the rotating armature. The principle was the same as used by Page and Pacinotti, but it was applied in most convenient form, and gave really continuous current, whereas all former machines gave either alternating currents or a rapid succession of currents in the same direction —tandem currents, they may be called. To recall a little of the more recent history of the magneto-electric machines then known, — Siemens in 1855 had made the long bobbin-armature wound from end to end; Wilde had used a little machine on this plan to excite a big electro magnet to make a second bobbin revolve, and had secured 1,500 revolutions a minute in the main armature.

Next came the Gramme armature. Gramme was a Belgian engineer whose invention consisted in using for the core of the armature a soft iron ring, placed between the horseshoe magnet poles, and in the same plane. This turns around its own centre, in that plane —as a top spins.

Being between the magnet poles and within their



GRAMME'S MACHINE

The armature A carrying a number of separate section coils connected in series, was rotated by hand in the first machine.

influence, this ring has always two poles, each the opposite of that of the near pole of the magnet — and two neutral points between, on the circumference. Round the ring are coiled the insulated wires, in section coils wound in the same direction, and connected in series, forming a continuous circuit spirally around

the ring. Each coil (a part of the main coil) as it moves toward the pole of the magnet develops an induced current, stronger as it approaches the pole. Then as it passes this current decreases, but *as the other end of this little section is now toward the magnet pole*, the current is in the same direction as before. Another coil follows, the same action is repeated, and so on — the current being always in one direction. But the other half of the coils are meantime being influenced in just the opposite way, as we shall see. Suppose as they go around, the coils are proceeding north-pole end forward. Then considering any one coil we shall have it approaching its north pole to the south pole of the magnet; it passes, and then has its south pole toward the south pole of the magnet. At the beginning of the second half of its revolution, it is approaching with its north pole toward the north pole of the magnet, then passes and has its south pole toward the north pole of the magnet.

But as the armature is turned, currents are created. The *first* half revolution first brings unlike poles together, and then separates like poles; the *second* half revolution first brings like poles together, then separates unlike poles. Thus, by Lenz's law, the two induced currents are in opposite directions; but each being continuous and uninterrupted, they are united by *two* commutators into a single continuous current.

Of course it must be understood that we can only give the action in the very crudest and simplest form, in order that it may be understood. But the Gramme armature was the beginning of an enormous improvement in these magneto-electric machines that preceded dynamos and motors.

In the next year, 1865, came a great improvement in another form of electric machine — of the class developed from Von Guericke's sulphur globe, Newton's glass globe, and the frictional machines that followed in the eighteenth century. These had, though bettered, remained in essence the same machine Ramsden invented — a glass disk with rubbers, collecting points, prime conductor, and all. There had come in 1775 Volta's electrophorus — the resinous cake already described. But now came a long step forward — made in a way that seems almost inevitable in all machines. Instead of a plate applied to another plate, and lifted — *reciprocating* motion — there was to be *circular* motion applied to the same purpose. Earlier experimenters had improved on the crude electrophorus, but though some of them (Darwin and Nicholson being named in the "Britannica") used rotary motion, the purpose was not fully followed out. But in 1860, Varley devised an electric machine the principle of which was excellent. It consisted of an insulating disk bearing on its edge or circumference conductors or electricity carriers. These at opposite ends of a diameter pass into two hollow conductor-cylinders slit to receive the carriers.

Inside each cylinder are two metallic springs, one connected to the cylinder, the other connected to earth. Supposing a small *positive* charge to be in one cylinder, as a carrier is revolved into that cylinder, it receives the charge, and, like the electrophorus plate, being touched by the earth-connecting spring, carries away a negative charge until it comes to the other cylinder, where being inside a hollow conductor it gives up the charge to that conductor through its

spring. Then it receives a positive charge at the other spring, and goes on to the first cylinder again.

In short, the apparatus amounts to having a number of little electrophoruses on the edge of a disk, so arranged as to be charged and discharged by the cylinders — the strength of the charges always increasing by accumulating.

This is the principle of the "induction machine." And it was soon greatly improved in form. The "most remarkable as well as the most useful of these machines" is that made by Holtz.

Holtz's induction machine has two glass disks set closely side by side and upright, one fixed, the other rotated. The fixed plate is slightly larger, and this fixed plate has cut through it two holes at the ends of a diameter, back of each being glued pieces of paper, with blunt "tongues" extending through the holes and nearly touching the moving plate, which rotates opposite to the pointing of the tongues. These pieces of paper collect current, and opposite them are brass rods ending in balls, but having comb-points toward the papers. These brass rods slide in holders.

The balls on the rods being brought into contact, a rubbed rod of ebonite is touched to one, giving a *negative* charge. Then they are separated, and the rotating wheel is turned. A positive charge is induced in the wheel, is taken off by the points, and is shown by sparks between the separated ball-ends.

This machine is hard to explain in every detail without diagrams, but the principle of it can be understood without that, for it is the same as the little electrophorus. The negative charge induces a positive charge in the other brass rod. This escapes by the

points to the paper, by the tongue of the paper to the wheel, is carried round to the other tongue, where it makes the other paper *positive*, which induces a negative charge in the first rod — and thus the accumulation goes on increasing, except (a very important exception) the losses into the air which must be greater as the tension (the pressure, or the electric potential) increases.

An increase of the number of disks and so on, makes more and more powerful machines, enabling very long sparks to be sent between the rods, or enabling heavy charges to be collected in Leyden jars or condensers. Such a multiplied Holtz machine is the Wimshurst Influence Machine, but it is also made simpler.[1] It has two plates of glass covered with shellac, and revolving in opposite directions. Both carry strips of tin foil glued on radially. These are touched by brushes, that conduct away the induced charges. The brushes are connected with the rods or electrodes. Practically there is always some little electric charge in the tinfoil strips, and as these are revolved, the brushes conduct away the charges on the two opposite plates, so that a difference of potential arises and is constantly increased as before.

This difference of electric state — difference of potential — is what causes the passing of the electric current from one thing to another, and these influence machines are mechanical contrivances for increasing a small difference. It is as if there was a slight difference of level between two pools of water in the course of a stream. By removing water from the lower, we

[1] See illustration on page 52.

increase the difference of level, and more water flows. Or suppose a tank connected with another tank by a pipe connecting them at the bottom, and suppose the first tank to be supplied by apparatus that flows the faster as the tank is emptied. Then we drive a spigot into the second tank. As the water flows out, there is a difference of pressure, the first tank begins to flow to the second, then the first tank receives a supply from the apparatus for filling it, and so on. This is like the induction machines.

In the great advance of electrical science, the trans-Atlantic cable was never forgotten.

Despite the failure of the first Atlantic cable after it had transmitted messages for a short time, and the general apathy toward renewing the enterprise, Mr. Cyrus Field and his British backers had by no means abandoned it.

The British Board of trade having appointed a committee of eminent engineers to report on the matter and having received in 1863 a favorable report, the capital was secured to renew the attempt to lay a permanent cable. July 15, 1865, saw the sailing of the *Great Eastern* with a new cable between three and four times as large as that of 1858.

There were slight delays and troubles at first but they were remedied. One deserves mention. *Twice* a short piece of wire was found to be driven through the insulation by some scoundrel — probably to cause a fall in the price of the cable company's stock. The cable had been laid to a distance of a thousand miles and more when it broke and sank. It was grappled, raised, but fell again to the bottom, and had to be abandoned for the year — a loss of $3,000,000.

This subject of cable-laying deserves a book to itself, for it is a most notable combination of human learning, engineering skill, and brave seamanship; but we are mainly concerned with the electric problems arising after the cable is laid successfully.

In 1865 Clerk Maxwell, whose researches upon electricity have been as fruitful as those of any investigator unless it be Faraday, announced a theory that light is an electric disturbance in the ether — an opinion that was remarkable at the time, but is now generally accepted, and considered as no more than a special case under a more general law including the phenomena of heat, light, electricity and radio-activity. It cannot be discussed here, since it has been so much more developed in our own time. Another discovery of this same period, about 1866, was also to be used later. Varley, of whose cell we have spoken, noticed the resistance offered to an electric current by a mass of filings until the current was established, and explained it by the setting up of conducting paths as the filings were electrified and attracted one another. This observation was to prove of great use afterward in wireless telegraphy, as will be seen.

CHAPTER XVII

CABLE, DUPLEX, AND DYNAMO

THREE happenings of 1866 were to help greatly the advance of electric science — the consolidation of several smaller companies with the Western Union, bringing together a large amount of capital interested in telegraphy and kindred subjects, the successful completion of the Atlantic cable, after so many trials and tribulations, and the invention of a still better electric machine by Wilde.

The Western Union by the absorption of the American Telegraph Company and the United States Telegraph Company became a well centralized powerful corporation with the management located in New York City, and owning 75,000 miles of wire, operating 2,250 offices, and sending between four and five million messages a year.

The final successful Atlantic cable expedition left England in 1866, the *Great Eastern* again being used. On the 13th of July the voyage began, and on the 28th the ocean cable was spliced to the shore end at Newfoundland, and once more America and Europe were joined, this time with a bond destined to endure for long service. The delight of the engineers and their brave helpers may be brought nearer to our understanding by reading this extract from the diary of Sir Daniel Gooch, the English engineer, expressing his feelings on making the successful landing in Newfoundland in July, 1866: "Is it wrong that I should

have felt as though my heart would burst when that end of our long line touched the shore amid the booming of cannon, the wild, half-mad cheers and shouts of the men? It seemed more than I could bear. How many anxious hours has the realization of this day cost me; yet I am rewarded. I am given a never-

THE GREAT EASTERN LAYING THE ATLANTIC CABLE (1866)

dying thought: 'That I aided in laying the Atlantic cable.' . . . When the cable was landed at Heart's Content there was the wildest excitement I had ever witnessed. The old cable hands seemed as though they could eat the end; one man actually put it into his mouth and sucked it. They held it up and danced round it, cheering at the top of their voices. It was a strange sight — nay, a sight that filled our eyes with tears. Yes, I felt not less than they did. I did cheer: but I could better have silently cried."

It is an interesting fact, and one not unimportant in regard to its electrical bearings that, while making experiments in regard to the least quantity of current

that would operate the receiving instrument at the other end of the Atlantic cable, an English operator at Valentia in Ireland made a voltaic cell out of a lady's silver thimble, using only a little acidulated water and probably a tiny bit of zinc — though the zinc is not mentioned in the article (from the *Electrical World*). This little cell was able to give current enough to operate the cable; but we must not forget that the difference of potential is what causes the current, and this is as great in a tiny cell as in a big one — the little one is less only in volume of current.

The operator at the American end of the line next took his turn in microscopic cell-making. He used an old percussion cap — of which a dozen might go into a thimble — looped a fine copper wire about it, fastened a minute strip of zinc to another copper wire. A drop of acidulated water filled the gun-cap cell, the end of the zinc was inserted, connection made with the cable and the earth, and signals were transmitted.

It is said that the English operator at the other end reported the signals as "awfully small," but the battery did its work across the 2,000 miles. The American operator at Heart's Content, Newfoundland, was William Dickerson, of the Anglo-American Telegraph Company; and he afterward gave the tiny battery to H. H. Ward, of the Western Union. Perhaps the greatest wonder of the occurrence is the perfection of the cable and its instruments.

The third achievement of 1866 was Wilde's electric machine, which used a small machine with permanent magnets to excite electro field magnets; thus adopting Hjorth's principle of eleven years earlier, and be-

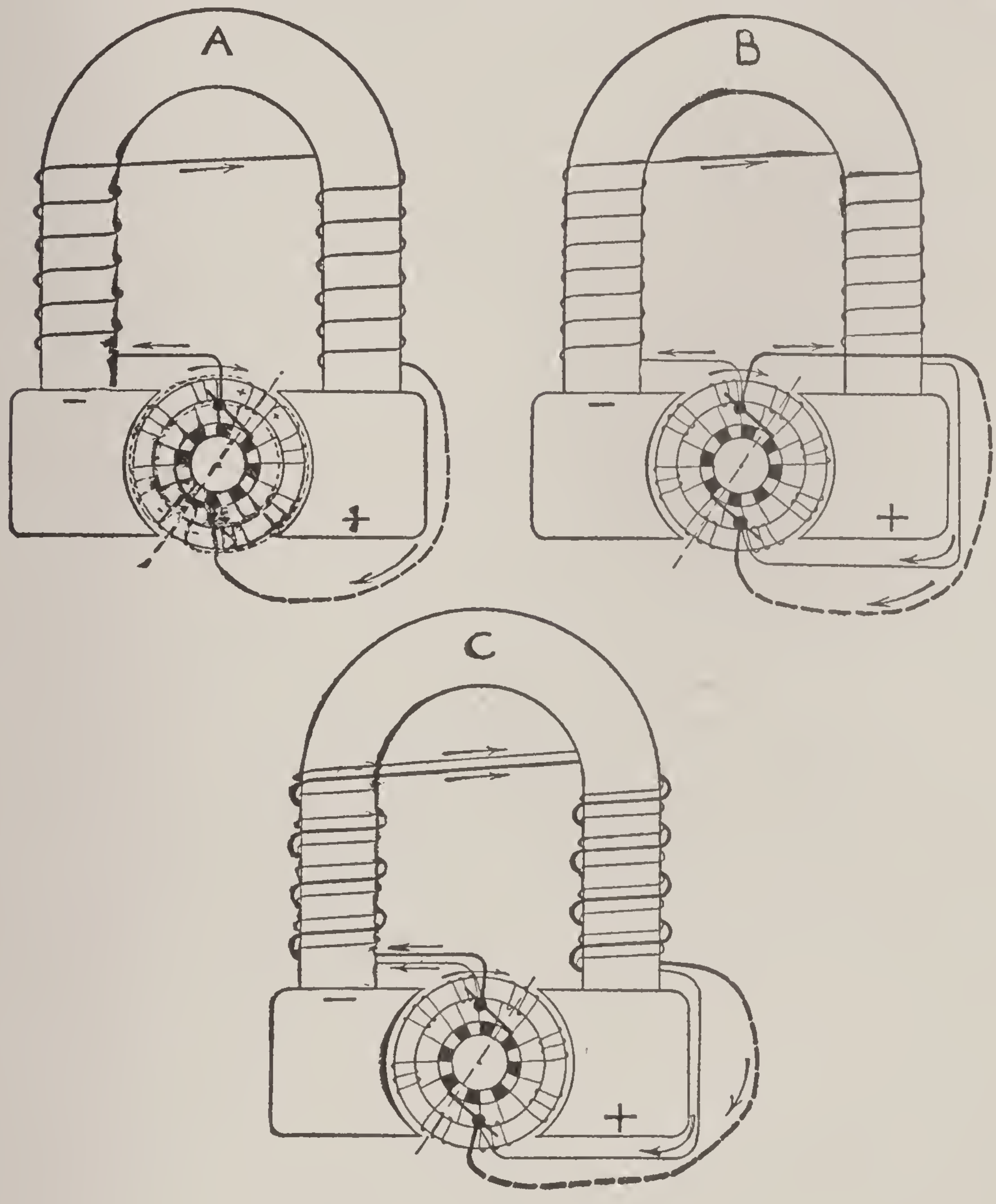
coming the forerunner of the self-exciting type of dynamos. Wilde also made later a triple machine, using a small permanent magnet machine (or as it is generally called, a "magneto machine") to magnetize the electro-magnet of a larger machine, which in turn magnetized a third electro-magnet.

Guillemin says that this required an engine of fifteen horse power to put it in movement, but yielded an enormously strong current, melting a heavy bar of platinum.

But in December of 1866, Varley patented a machine that did away with Wilde's "exciter" or permanent magnet—thus divorcing the permanent magnet from the dynamo. Varley, Wheatstone, Moses G. Farmer and Dr. Werner Siemens at about the same period seem to have hit upon the idea that the electric machine contained enough difference of potential to magnetize its own magnet from the beginning. At all events, in 1867, machines on this principle were made by all three or patents taken out. All had discovered that if the armature was set spinning, as it cuts the lines of force coming from the electro-magnet—no matter how weak these may be,—currents are caused in the armature coils, are transmitted through the electro-magnet coils, and a "building-up process" takes place. Soon a high degree of magnetizing is accomplished, and when the dynamo is fully charged, it runs with great resistance, furnishing a strong current, precisely as if a permanent magnet starter had been employed.

It will be seen that this self-exciting is done by connecting the armature coils with the electro-magnet coils, and using the armature current to produce mag-

netism. But this can be done in three ways: (1) All the current can be passed around the magnet. (2) Part of the current can be taken around the mag-



DIRECT CURRENT DYNAMOS

A—Series-wound. B—Shunt-wound. C—Compound-wound.

The armature revolves between the pole-pieces, marked plus and minus. The heavy dotted lines indicate the external circuit which takes its current from the commutator.

net. (3) Sometimes all and sometimes part can be used. These three forms are known by the names, series-wound; shunt-wound; compound-wound. Three kinds of windings accomplish these results.

Suppose the current from the dynamo is to go to a set of arc-lights. Then, if we connect the armature coils first to the coils of the magnet, conducting the whole current around it, and then to the lighting system, we have a series-wound dynamo. If we connect the armature coils first with the lighting system, and then let a side connecting wire run to the coils of the magnet, we have a shunt-wound dynamo. If we take a series-wound dynamo, and then add the shunt wire, so we may use either or both, we have the compound-wound dynamo.

Each of these forms of dynamo has its own advantages and disadvantages, and is adapted to special uses.

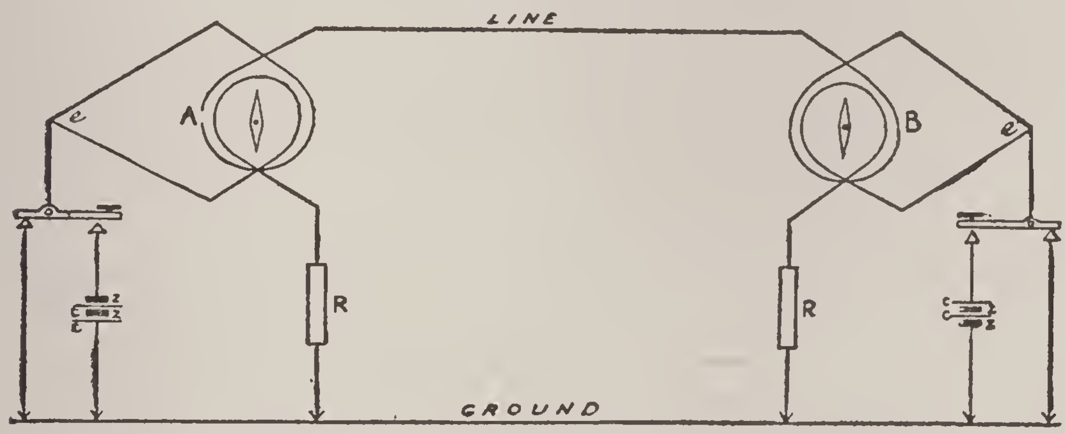
In 1869 came the report of the committee appointed by the British Association to fix and name the Standard Electrical Units but the final adoption of a uniform international system did not come until 1881.

In 1872 the duplex telegraph was perfected by Joseph B. Stearns, of Boston, being covered by two patents issued in that year, which set Thomas A. Edison to work upon an improvement of the system.

Edison was at this time twenty-five years old. Born in 1847, in Ohio, he became at twelve a train-boy, and at fifteen printed a small paper on the train, circulating it among the employees. Having saved the life of a child, he was taught telegraphy by the father and became an operator. At seventeen he invented an automatic telegraphic repeater, for transmitting a message to another line. But for so active a brain the confinement of the telegraph-key was unbearable, and he became known as a skilful but nomadic "tramp" operator.

His success came to him as the result of inventing a commercial stock indicator which he sold for $40,000; and with this money he established his first laboratory at Newark, New Jersey, and began his career as a professional investigator and inventor.

In 1873 there was an industrial exhibition in Vienna and among the exhibits were a number of machines including a magnetic motor and a Gramme dynamo, arranged in a group so that there might be



DUPLEX TELEGRAPHY—STEARNS-EDISON METHOD

At A and B are the receiving and transmitting instruments, differentially wound, one coil of A being connected to that of B, while the other is connected with the rheostat R and R. If then both keys are simultaneously depressed, the currents sent will strengthen each other. If only A be depressed the current will branch at *e*, dividing equally between the differential coils at A, and causing no deflection of the needle. At B, however, the current can only pass through one of the windings, and thus make a signal at B. The letters C Z show the battery connections.

shown examples of their various uses as generators of electric currents and in working machinery. Some were to be run by a number of belts from an engine-shaft. Then occurred one of those accidents that properly observed and used lead to industrial progress. A workman happened to attach two wires from a running dynamo to the magneto-electric machine that had not yet been set in operation by the belting from the engine-shaft. To the workman's surprise the idle machine at once began running backward at great speed. Gramme, the inventor, was summoned, and he

at once saw that the second dynamo had been made a *motor*.

Now this was not precisely a new discovery, for as Professor Houston points out it was "certainly known to Lenz in 1838" that the same machine would act either as dynamo to produce the current when run by power, or power (mechanical motion) when set in revolution by a current. Jacobi in 1848 also knew this, and Pacinotti, the Italian, mentioned it, as did Siemens in 1867. But something was needed to show the principle clearly and publicly, and this happening at the Vienna exhibition — whether accidental, or, as one account makes it, the result of an ingenious attempt to make up for the failure of two batteries to work the magneto-electric engine — was a public demonstration that the current from a dynamo could be readily conveyed to another dynamo and would make it into an efficient motor.

The story that the connection of the two was not accidental is given in Houston's "Electricity in Every Day Life," and seems the more probable for this reason: Fontaine who made the connection says that the connecting was done by means of a conducting cable 250 metres in length, — and that notwithstanding the resistance of this long conductor, the second machine was set into so rapid a revolution as to work the pump attached to it much too violently. Fontaine therefore interposed still more cable — over two kilometres — to increase resistance and thus decrease the speed.

This proof of the Gramme dynamo's power to work another dynamo *through a long conductor* seemed to be just the demonstration needed to set inventors to

work upon using so convenient a means of conveying power to a distance — which, then at least, owing to the lack of economy of motors as compared to steam-engines, would be the chief reason for perfecting the motor-use of dynamos. The principle, in short, was not new, but its practical application on an industrial scale was first clearly shown in June, 1873, and thus became a distinct step in the evolution of electrical arts, for it at once led to projects for electric-transmission of power on a large scale, and especially to railway propulsion.

The quadruplex system of telegraphing was invented and brought out by Edison in 1874. This allowed two messages to be sent each way at a time over one wire. But in order to understand this there is a missing link to be supplied. Duplex telegraphy we have explained as the sending of two *opposite messages* on the same wire at one time, and, it will be remembered, is done by dividing the current. "Diplex" telegraphy, on the other hand, is the sending of two messages at one time *in the same direction* on one wire. As quadruplex telegraphy combines these two, diplex telegraphy must first be understood. It was first worked at by Dr. J. B. Stark of Vienna, and then improved by others, but finally brought to success by Edison. The principle of diplex is to have at the far end of the line two receivers, one worked by strong currents only, the other responding only to a positive (or a negative) current, and being unaffected by the other.

As to the strong and weak current receiver, it is so arranged with resisting springs that it is not affected by the weak current; for this is not strong enough to

operate the relay that works the receiver. Only when a strong current moves the relay armature is the circuit to the receiver closed so it will receive the signal.

The other form of receiver has a *polarized* relay (invented by Siemens) that will respond only to (say) the positive current, while the negative current does not move it. This relay consists of an electro-magnet wound in opposite directions on the two poles, so that they have their ends both of the same polarity. Be-

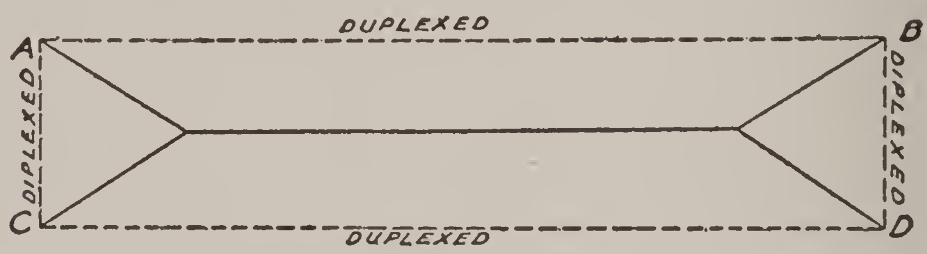


DIAGRAM OF DIPLEX PRINCIPLE

A and B use polarizing keys. C and D use strengthening keys.

tween them is a steel bar, also magnetized, but with polarity opposite to that of the electro-magnet poles. It is thus attracted by both equally — and is free to swing toward either being pivoted like a compass needle. Upon the passage of a positive current one of the poles of the electro-magnet is strengthened, and the other weakened (their coiling being opposite), and the steel-bar moves toward the strengthened pole. Now if we put a stop to the bar on one side, leaving it free to move only toward the other — it will respond only to the current that strengthens one side. Therefore, by putting an obstruction between the bar and the pole that would be strengthened by a *negative* current, we can stop its tendency to move that way, and yet leave it free to be attracted whenever a positive current is sent.

This relay is often mounted upon a permanent steel magnet shaped like a capital C — the bar being hinged to the upper pole, and the electro-magnet being set on the lower. The permanent magnet helps the balanced state, strengthening both the polarity of the electro-magnet and that of the steel bar, without interfering with their response to the arriving currents.

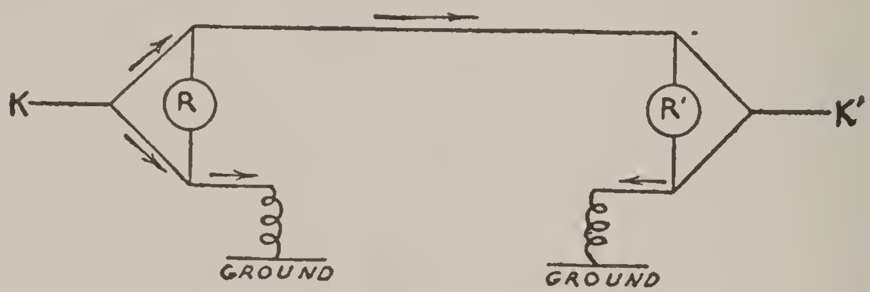
The transmitter to this form of relay is a key known as a "pole-changer," so arranged that it sends one direction of current when pressed down, the other when raised by a spring.

The polarized relay is made sensitive enough to respond to the positive weaker current used by the other operator (the "strong and weak" transmitter) but acts with either strong or weak positive current. So both the polarizing key, and the strong and weak key can send their signals without interference with each other. Through the line there is always some current passing. One operator is able to strengthen or weaken it at will by his key, and thus send his signal; the other cannot either strengthen or weaken it, as his key merely makes it positive (signaling) or negative (non-signaling). Of course the polarized relay can be prepared beforehand to respond to either the negative or positive current at will.

This in an uncomplicated form is the general idea of the way in which diplex telegraphy is accomplished.

There is also another form of duplex than that already described. This second form is based upon the employment of what is known as Wheatstone's Bridge — a device for measuring electric resistance of conductors. This "bridge" was invented by Christie,

and its use introduced by Wheatstone. Suppose we make a diamond-shaped line of conducting wires — that is, a parallelogram like the diamond spot on playing cards. From one point to another opposite we attach another wire, thus making two triangles joined at their bases thus : ◁▷ Then we connect the two wires of a battery at the ends thus : -◁▷- so a current flows through all the wires. Now we put a galvanometer inside the diamond and connect it to the ends of the transverse wire which is cut in the middle. Then the resistance of the two sides of the diamond — the upper and lower — being adjusted and made equal there is no current through the galvanometer, because



BRIDGE DUPLEX TELEGRAPHY

K—Transmitting keys. R—Receiver

current flows only where there is difference of potential. The adjusting can be done by putting thicker or thinner wire in the circuits. Now if we put in a piece of wire or connect at one quarter of the circuit some apparatus of which we wish to know the resistance, we try to restore the equality by balancing with known resistances put in the other corresponding quarter of the circuit. For example, we put a coil of insulated wire into the left half of the upper circuit, and find that it disturbs the galvanometer, since there is now more resistance in the upper half, and the potentials being different current flows from the higher to the

lower potential. We then put into the left half of the lower circuit wire lengths of different known (tested) resistances. When we have balanced the two halves the galvanometer will cease to show current, and we shall know the resistance of the insulated wire.

It is evident from considering this bridge or balance that it gives us a means of passing an electric current around a galvanometer without affecting it so long as the resistance of the two paths are kept equal in potential. If now we put a receiver of a telegraph line in place of the galvanometer, it also will be unaffected so long as the two diverging paths offer equal resistance and so are of equal potential. This is adapted to duplex telegraphing. Let the line from the sending station be divided by such a bridge with the home receiving instrument set in between the paths. Then the outgoing current will not affect that receiver, for half the current goes to the line on one side of it, and the other half goes to the earth on the other side, balancing that current. But the outgoing current when it reaches the other end of the line, goes *inward* past the bridge, and then to earth, passing the bridge in the other direction, and making a difference of electric potential. This causes a current in the far receiver.

Whether the far key current is turned on or off will make no difference, for it is either absent, or even at the bridge ends of its own receiver, and has no effect.

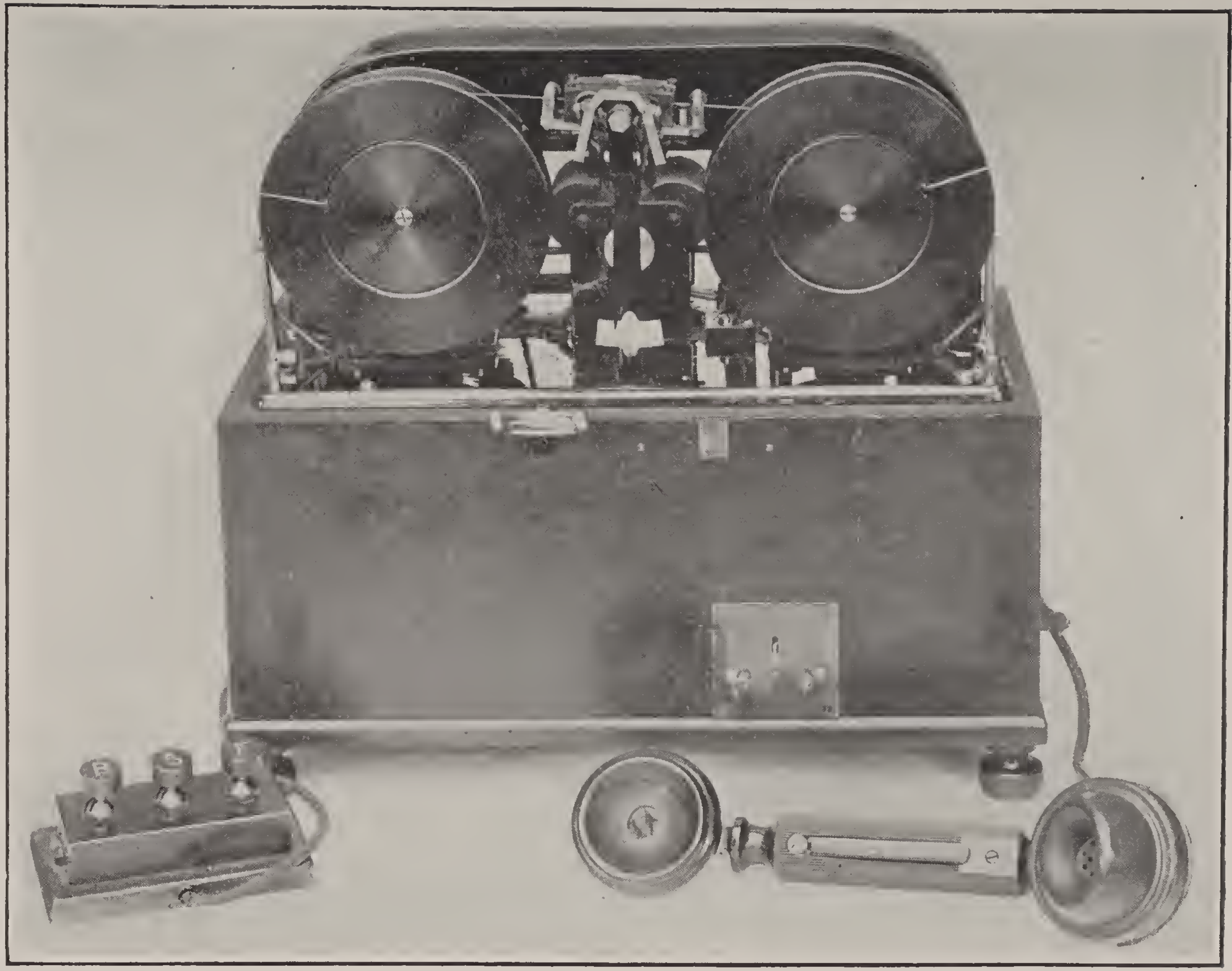
Now to apply all this to quadruplex telegraphy. First it may be said broadly that the duplex (either system) and diplex do not interfere, and so

may be combined. The duplex simply divides the current into halves, and makes these balance at home, while not balancing at the far station. Strong or weak currents may be equally well divided. The strengthening or weakening of the current, and the change of polarity of current may all be done as well with the half current. Therefore in the quadruplex we have in each station operators *diplexing* their own currents; and as regards the other two operators; their currents are *duplexing*. Thus we have A using polarity of current at his station; B using the same system and duplexing with A. C is with A, but is using only a strong current, thus diplexing with A. D is with B, also using only the strong current, and duplexing with C. Thus each operator is diplexed with his companion, and duplexed with his correspondent — all four can send messages at once by the same wire.

Of course the two receivers at each office are each attended by receiving operators — making four men in each office, all using one wire, and so the service is quadrupled, the wire used fourfold, and the line said to be quadruplexed.

The credit of making this system a practical everyday working system belongs to Thomas A. Edison, and his invention was made in 1874.

It is not pretended that the foregoing explanation will make the whole working of a quadruplexed line clear, but at least it will set forth the principle, and a study of the instruments at work will complete the knowledge.



THE TELEGRAPHONE
By courtesy of The Sterling Debenture Co.
(*See also page* 302)

CHAPTER XVIII

CABLE RECORDER, TELEPHONE, AND ELECTRIC LIGHT

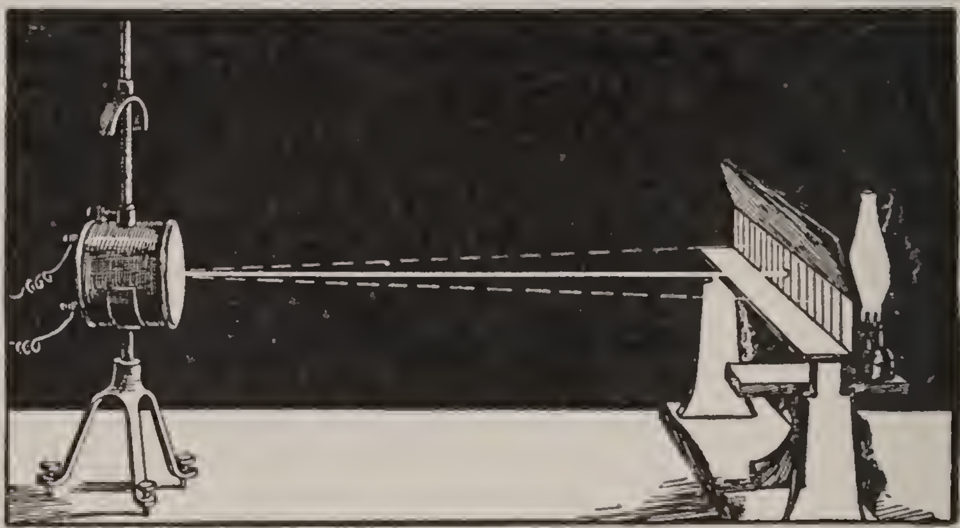
The problem of transmitting signals by a circuit such as the Atlantic cable is of course one entirely different from that presented by the land lines. In the land lines relays can be brought into play wherever needed, but the cable must be worked from end to end with a single force. The capacity of a cable is enormous, and all this capacity must be supplied before there is any action — any electromotive force — at the further end.

To some extent the problem had been worked out beforehand, but actual experience required some changes in the theory. The various trials of methods resulted in the general use of the mirror galvanometer — a modification of the old device used by Gauss and Weber in their telegraph in Göttingen. During 1858, for the one month's life of the first Atlantic cable, a mirror galvanometer as improved by Sir William Thomson was used as the receiver, and a still better form of the same instrument was used on the cable of 1866 and later.

This is an application of the deflected needle principle of Oersted, the apparatus being made as sensitive as possible.

Two magnetic needles are connected by a rigid frame with their poles in opposite directions, so they have no tendency to point any way more than another. This needle-pair is hung by a silk fibre, and attached

to each of the needles is a tiny mirror. Then a coil of wire is wound into the "shape and position of a vertical figure 8" (to quote from Tunzelmann's "Electricity in Modern Life"). This is made of very fine silk wound copper wire, so as to give many turns. If a current goes through the coil, each loop of the 8 acts on one needle, and tends to turn both in the same direction — either both in one direction or both in the other — as the current is positive or negative. This is called an astatic galvanometer.



A Form of Mirror Galvanometer, as Constructed by Sir William Thompson

The light from the lamp, placed before a slot in the screen, is reflected from a mirror, attached to the galvanometer-needle, the light thus being thrown back to the scale, at the right, and the signals being read by the movements of the spot of light, as it is deflected to the right or left by the swinging of the needle.

This enables the sending operator to turn the needles one way or the other, at will. As they turn they move their little mirrors, and these reflect a beam of light so that it is moved upon a scale — greatly increasing the slight motion of the mirrors. These are the essential parts of the apparatus.

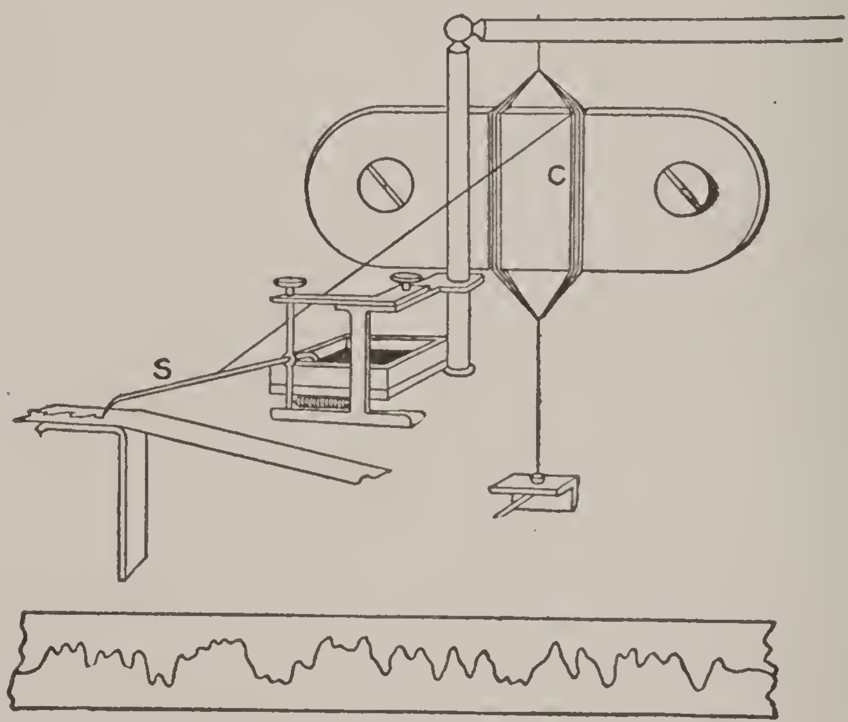
As to the transmitter, it has two keys. One con-

nects the cable and the positive pole of a battery, when pressed; the other connects the cable and the negative pole, when pressed. When either is not pressed, it connects with the earth. Consequently the operator can send into the cable either a positive or negative current. One turns the needles in one direction, the other in the opposite; and by watching the motion of the beam of light, that is, the moving spot of light on the scale, the message is read, for right and left correspond to the dot and dash of the Morse alphabet.

This form of apparatus is adopted for several reasons. First, because it is highly sensitive, acting even when only feeble currents are transmitted. Second, because signals by means of a non-reversed current — as given by only making and breaking circuit — would be far too slow. A long condenser like the cable, fills and empties slowly, and between each make and break, a long pause would be required while the cable cleared itself. The reversing helps the clearing greatly, though still the cable works more slowly than a short land line. Third, weaker currents will do the work with these instruments, and there is less danger of harming the cable's insulation if weaker currents are used. Fourth, the weaker the current employed, the sooner will the charge it sends into the cable be cleared when circuit is broken, or when the current is reversed. All these reasons explain why the ordinary instruments have been replaced by more delicate devices when the signals must be sent by means of a long submarine cable.

Both the cable transmitter and receiver have been improved by Sir William Thomson. He made the

transmitter automatic, operating it by a punched paper strip that exactly adapted the signals to the action of the cable, and attached to the receiver a device for recording its signals. This is known as the siphon-recorder, invented in 1874 — or patented then — "the most important invention relating to submarine telegraphs," as the author of "Progress of Invention in the Nineteenth Century" says. This is a light coil of wire so hung between the poles of an electro



THE SIPHON-RECORDER AND ITS RECORD

C—Coil. S—Siphon. (The record spells the words "Siphon-Recorder."

magnet as to be moved by the current coming through the coil from the cable. As the coil moves, it moves to and fro a light glass siphon that dips into a little box of ink, and this siphon almost touches a ribbon of paper moved below it. As the current comes and moves the coil it also moves the siphon by means of a connecting thread, and so makes a wave line. Thomson oppositely electrified the paper and siphon, so that the

attraction between paper and ink caused the mark; but a later inventor, Cuttriss, vibrated the siphon by electro magnetism, thus causing the ink to leave the end and this was an improvement on Thomson's apparatus, which tended to lose its electric charges in damp weather. To have siphon and paper touch would cause friction, and interfere with the movement of the coil.

If it be added that cables can be duplexed like land-lines, except that the exact balancing is much more delicate, we shall have brought the art of cable-telegraphy up to the date we have now reached. Diplexing and quadruplexing have not been accomplished with the weak cable currents.

In the beginning of 1876 occurred a remarkable instance of simultaneous invention. On February 14, within two hours, were filed two preliminary papers for telephone patents, one being in the name of Elisha Gray, the other in that of Alexander Graham Bell. Gray filed a caveat, Bell an application for a patent. Into the almost endless controversy that raged about the telephone invention he may enter who chooses to consult the special literature of the subject. It is enough for our purposes that to Bell was awarded the final victory, and to him seems to be due the really important features that produced the modern telephone. We may therefore at least consider his telephone the successful type, and shall describe its evolution without considering it necessary to make constant reference to those who had something similar in hand or in view.

Bell was born in Edinburgh in 1847, and is now nearly sixty. He studied in Edinburgh and London

Universities, and in 1870 went with his father to Canada where he was on a farm. In 1873, he became Professor of Vocal Physiology in Boston University, and in the course of experiments meant to make sound visible to deaf-mutes, he came to the conclusion that speech might be conveyed by electricity.

His early apparatus consisted of means for causing stretched membranes to move the armatures of magnets, or to move a bit of metal to and fro near the pole of a magnet. This set up slight disturbances in the magnetic field, and these were repeated in a coil attached by a long conductor to another coil around a magnet. The second magnet thus affected attracted or repelled a bit of iron attached to a second membrane, and so repeated the vibrations of the first.

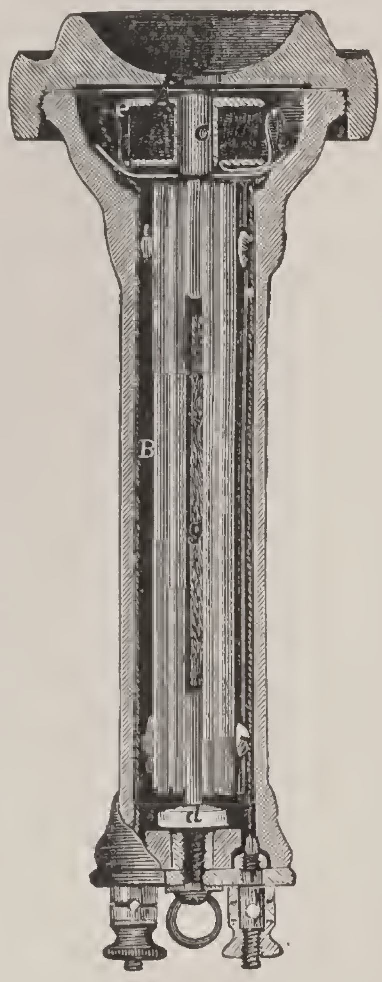
The first results were not wholly satisfactory though they seemed to prove the principle correct, but despite the protests of friends who believed he would do better to give his time to multiple telegraphy, Bell persevered, and finally attained success.

Bell's patent was granted on March 7, 1876. And not many months later he offered the apparatus as an exhibit at the Centennial Exhibition in Philadelphia. The judges were little impressed, but Dom Pedro, the Emperor of Brazil, happening to be present, requested a trial of the instrument, and his commendation secured a place for the new invention.

The apparatus exhibited was very simple, and yet it had the essentials of the modern telephone-receiver — which will act also as a transmitter, though in that use it has been bettered. A straight permanent magnet is surrounded by a coil of insulated wire. In

front of the magnet is a metal diaphragm. Speech makes this diaphragm vibrate. As it approaches or recedes from the magnet, it induces electric currents in the magnet and coil — as we know from Faraday's experiment, the foundation of all inventions based on induced currents. These currents, conducted to the coil of a similar instrument, cause the strength of the other magnet to vary, set the other diaphragm in motion, duplicating the motions of the other diaphragm, vibrating the air as it was vibrated at the other end, and so reproducing the sounds.

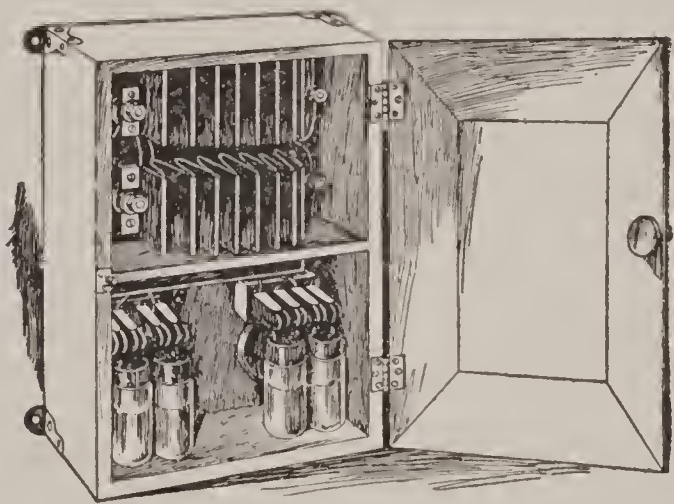
Of course these secondary motions were feebler than the original motions, since there was a loss of power all along the line, by the friction and resistance of the parts, and so on. But the talk was repeated, and later inventions corrected the faults.



Bell Telephone
A—Diaphragm of thin ferrotype plate. B—Compound magnet. C—Soft Iron pole-piece.

Three minor advances also belong to the Centennial year. One of these is Edison's electric pen — a cylinder like a pencil, in which a point is kept in vibration with great rapidity by means of electricity acting through magnet coils on a tiny circuit breaker. The point made punctures in paper as it was moved in writing, and then the paper could be used as a stencil. Later devices for copying have superseded this clever device.

The second was the increased use of the electric light in photography, and the third was also Edison's — an electric meter based on the principle that an electro current deposits metal in an electrolytic bath according to the amount of current passing through a solution — the principle discovered and announced by Faraday in his voltameter. Edison's apparatus was simply twin voltameters in a locked box (each being used to check the other's record). When current passes through the zinc plates in the solutions of zinc sulphate, there is new metallic zinc deposited on the plates, and



EDISON'S CHEMICAL METER

This device played an important part in making the use of electricity commercially possible.

the amount thus added is greater or less according to the current and the time it lasts. By weighing the zinc plates, the gain in zinc serves to measure the current, being proportional to it. The meter is put on a side or shunt circuit, but the relation between the main current and the shunt being known, the amount of electricity used in a house or factory or by a machine or a lighting circuit could be known, and, if sold, charged for. To keep the temperature

above freezing, a tiny lamp was put into the box, and automatically lighted or put out as necessary by a conducting expansion bar that made electric connection with the lamp.

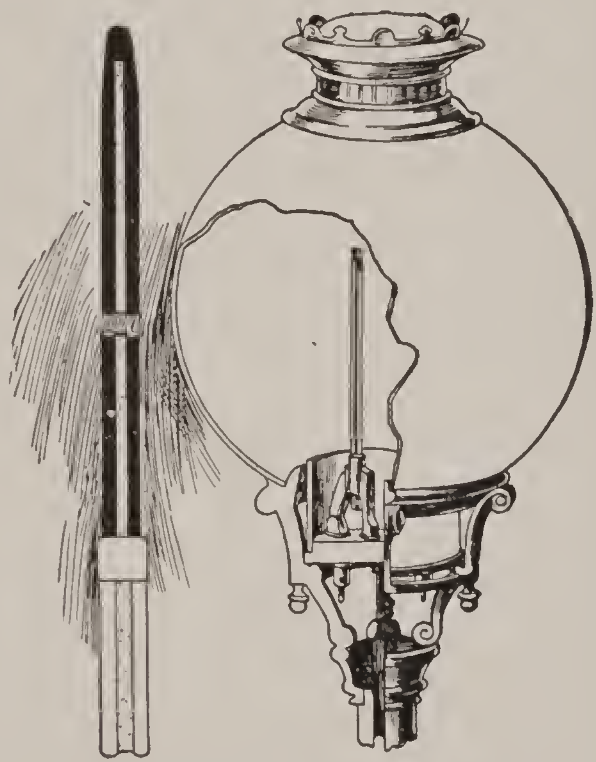
This was a help to the establishing of companies selling electricity. A later meter caused the increase of weight in the measuring plate to operate a mechanism. The means employed was a balance, to the ends of which the two plates were hung. As one plate increased in weight it overbalances the other, and the beam of the balance descended — at the same time reversing the direction of the current by moving a switch. Then the other plate received the deposit until it descended in its turn. As the beam moved it recorded its motions on dials by clockwork. This was not entirely a new principle, but an adaptation of a device used in electro-plating.

Other meters have used a moving pendulum, kept in motion by electricity, or an electro-motor that turns a governor like that on a steam engine, and raises the governor arms against the pull of an electro magnet put below, but these are only ingenious pieces of mechanism, using no new electrical principle.

In 1877 was invented Jablochoff's electric candle, an arc light burning carbons in a new way. Before this time complicated mechanism was used to keep the carbons at a fixed distance apart so that the arc would be maintained. Jablochoff, a Russian officer, was clever enough to see that the carbons need not be driven tandem in order to come end to end. He put his carbon rods side by side, separating them by a strip of insulating material that would burn away only just by the arc. Once lighted by the passing of the cur-

rent, the lamp would burn steadily, destroying the insulation (kaolin — a kind of china-clay) and exposing the carbons as required. As to the lighting, this was provided for by connecting the tops of the carbons by a small strip, that subsequently burns away.

But the two carbons burn unequally. First he made the positive, or quick burning carbon, thicker; but this made the resistance of the thinner carbon greater, and it burned too quickly. Therefore he simply used the



The Jablochoff Candle (1877)

alternating current and carbons of equal size — causing them to be equally consumed. This was very convenient, for the ordinary electric machine then in use gave the alternating currents.

Next the kaolin (which melted at the arc, and when melted became an incandescent conductor — using up much current in heat) was replaced by a mixture of sulphate of lime two parts and sulphate of baryta, one

part. This burned to a vapor, and as a gas increases the light, and is as easy to make as plaster.

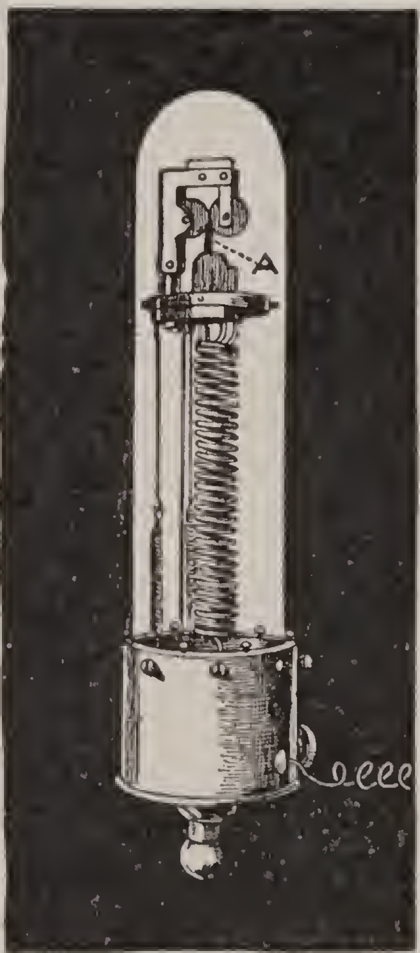
Though still subject to some faults the light was practical and serviceable, being much used. The main difficulty was to prevent the cracking of the insulation, for cracks made short circuits, and to keep its consuming even with that of the carbons so these should have the arc only between the points.

Each candle burned two hours, and then the current could be switched to another. Later this switching was done automatically. Usually four were in each group — as in the Avenue de L'Opera, Paris, and thus burned eight hours. Many improvements in the mechanical features were made, and the Jablochoff candles found extended use in Europe and to less extent in America.

CHAPTER XIX

SOME USES OF CARBON

Another light of the same period is the Sawyer-Mann lamp in its earliest form, which used an incandescent conductor in a globe of nitrogen gas but their improved lamps were not patented until 1880. In 1879 Moses Farmer also brought out a carbon lamp in an exhausted globe and lighted a house at Newport with it, but all these lamps were soon to be superseded by the better form using a carbon filament invented by Edison about 1879 and 1880 and later.



The Sawyer-Mann Lamp
A—Incandescent Conductor.

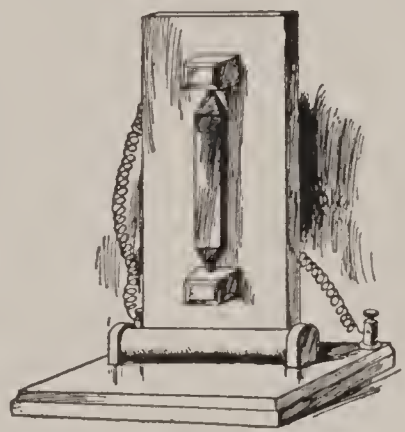
But earlier than these came two improved telephone transmitters — those of Berliner and Edison. Berliner filed application for a patent in 1877, but as his right was contested by Gray, Edison, Bell, and many others, it was not granted till 1891. To disentangle the claims would require experts and patent lawyers, but the credit of the improvement is usually given to

Berliner and Edison. The general principle back of the invention lay in the discovery that carbon varied its electrical resistance enormously under very slight pressures. This is due to the French physicist, du Moncel, who found that in the contact of two conductors the resistance is proportionate to the lack of pressure; and also to Professor Hughes of England, inventor of the printing telegraph and of the microphone in 1878. He discovered in a course of experiments that when substances of high resistance were in a circuit in loose contact their conductivity became much increased by even the slight pressures such as were caused by vibrations. On this principle he made his microphone. Fixing two carbon blocks in a support made of a block of wood he set upright between them a double pointed stick of carbon, the points resting in little holes in the other carbons. To the supports were attached wires leading to a telephone receiver, and the battery — all three being in the circuit. Now even the smallest sound vibrations are found to change the resistance of the carbon very greatly, to cause *magnified* vibrations of the diaphragm in the telephone, and so to be heard as if through a magnifier of sound. Just as microscope means a viewer of small objects a microphone means a hearer of small sounds, and even a fly's footsteps could be made plainly audible by a proper apparatus.

Both Berliner and Edison, as well as Hughes and others, promptly set to work to combine the induction coil and the microphone feature with the telephone-transmitter — where the sound-magnifying power was sorely needed. It should be mentioned here, as Professor Houston suggests, that the first telephone-

receiver — Reis's — was really a form of microphone instrument.

But we cannot go into the history of the various inventions that made up the receiver finally adopted, nor can we show how the microphone itself was increased in power and in its applications by multiplying the rods of carbon and other means. About 1880 the increase in electric inventions and applications and combinations of known methods to new purposes was so enormous that we must resolutely confine ourselves



HUGHES' MICROPHONE

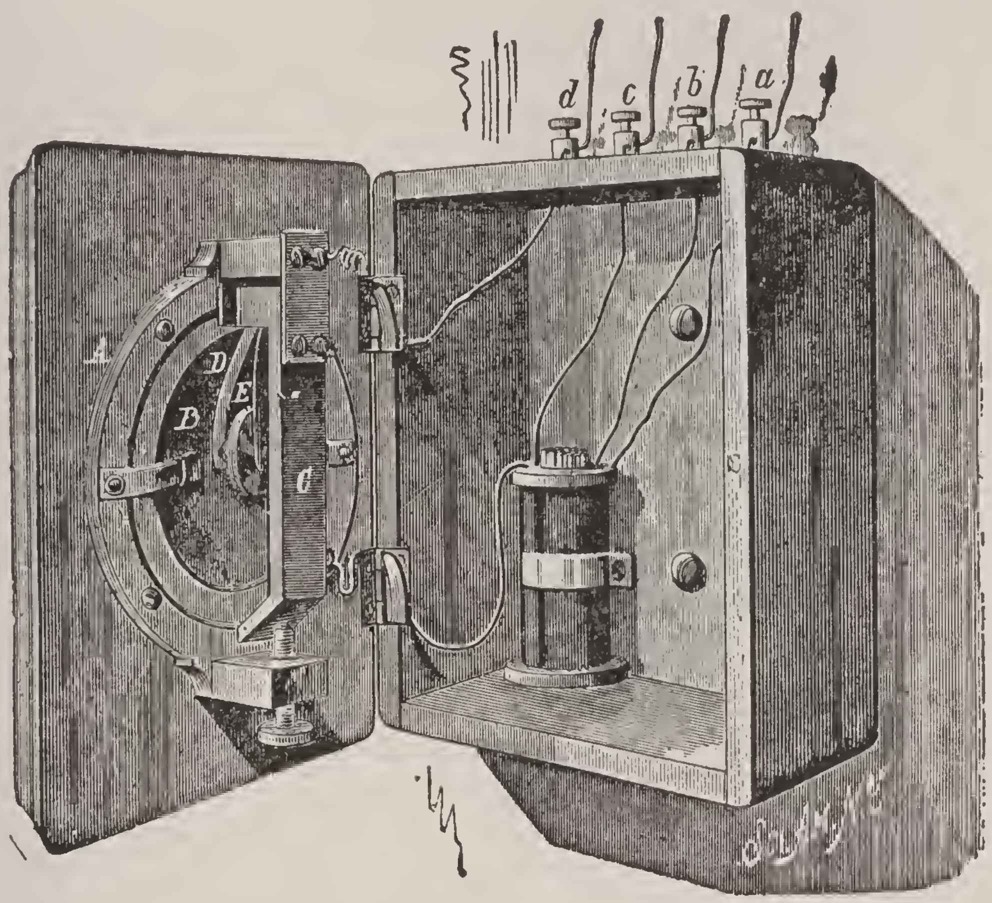
In this instrument, a rod of carbon, pointed at both ends is loosely held in two small holes in blocks of carbon at each end, supported on a wooden sounding-board. These blocks are connected in circuit with a voltaic battery and if a telephone receiver is then placed in the circuit, talking or singing can be plainly heard through it.

to the main steps of advance, leaving to technical students the study of special departments.

But the new telephone-transmitters were of vast importance, and in order to show what they were we shall give a few moments to the commercial forms of these instruments — mentioning, however, that there are numerous other effective forms.

The Blake transmitter is a mechanical adaptation of the principles of Hughes's microphone and of the induction coil as applied to the telephone by Berliner

and of the carbon-button transmitter invented by Edison, and is still in use. It is the apparatus contained in the familiar box of the telephone that is fastened to the wall. Opening the door one finds it to carry a diaphragm in a circular iron frame, and this diaphragm is supported on one edge but free to move and vibrate. In front of it is a microphone, con-



THE BLAKE TRANSMITTER

A—Cast iron ring. B D—Diaphragm. C—Casting to support diaphragm. E—Spring through which connection is made. a b—Binding posts for battery terminals. c d—Binding posts for line terminals.

nected by means of a platinum rod on a spring, which rod touches diaphragm and microphone. Inside the box rests an induction coil.

The primary wire of the induction coil is connected with the transmitter, the secondary wire with the line.

We speak into the mouthpiece, its diaphragm vi-

brates, and sends induced currents through the microphone and the primary wire of the induction coil. The induction coil then sends the impulses through the line to the other telephone-receiver, being aided by a heavier charge afforded by a battery. This battery though it operates the induction coil does not prevent the currents from being modified by those sent through the microphone.

If the reader will carefully consider the telephone from beginning to end, he will see that the apparatus combines in one apparatus the discoveries and inventions of dozens of investigators of whom we have spoken — from the Faraday induction coil (to go no further back) to Professor Hughes's microphone. By 1878 the first telephone exchange was in operation, the first long line — Salem to Boston — having been built the year before. That was long for those days, but the growth has been so rapid that it seems a trifling distance indeed.

About 1878 also Edison introduced his carbon-filament lamp, having to meet an interference claim in the Patent Office with Sawyer and Mann who also claimed the invention. But the courts in 1892 awarded the invention to Edison. He had begun to study the problem in the thorough way that has made him so successful, on his own principle that inventive genius is "one-third inspiration, two-thirds perspiration." He cleared his laboratory of all the telephone and phonograph materials, and set to work to solve the problem of practicable electric lighting. He turned from the arc light because it was not possible to make it steady, and studied the incandescent light. He found it needed an incandescent substance that

would be cheap, lasting, offer the right resistance, and be ductile enough to form fine wire-like filaments. Another most important need for the filament was that it should be "refractory" — that is, be able to be heated to a very high degree for a long time without being destroyed or fused. He tried platinum and other rarer metals, and made successful lamps with platinum filaments; but it was not satisfactory.

Edison then experimented upon various forms of carbon, and made the carbon from all sorts of fibres, and at last resolved to try natural wood fibres, charred to carbon. He sent men all through the world, collected fibres and tested them patiently, at last choosing bamboo. Then the different kinds of this wood were tried in the same exhaustive manner and a certain Japanese bamboo selected as the best. But this was a little later than the period we have reached.

In 1879 the first actual electric railway run from a

Siemens's First Electric Railway, Berlin, 1879

central station was established in Berlin, but only for showing the principle at the Industrial Exhibition. It was a circular track about 1,000 feet long, and the dynamo supplied about five horse-power. This railway had been designed by Dr. Werner Siemens at the request of a mining company. It carried thousands

of people during the exhibition. Next in order came Edison's dynamo railway at Menlo Park, in 1881. Both the Siemens and the Edison railways were run by electric current transmitted by a rail, the Siemens railway taking power from a third rail between the others. But the patent office granted to Stephen D. Field in 1891 a patent, based on a caveat filed in 1879, for operating a railway by a current conducted through the rails to a motor. The Field and Edison interests had earlier joined forces, and in 1881 and 1883 railways on their designs were run in Stockbridge and in Chicago at a Railway Exposition. The current furnished by a shunt-wound dynamo followed a central third rail, operated a motor on the same plan as the dynamo, and then returned to the station by the other rails. But there were no commercial street railways in operation until 1885.

Meanwhile in 1882 and 1883 other inventors had used a suspended wire for bringing the current from the central station to the motor, and the cheapness and handiness of this system (introduced by Dr. J. R. Finney of Pennsylvania), was to give it an enormous advantage, though Finney's trolley-wheel was connected to the motor through a flexible cord, and is said to have worked well only at moderate speeds; but this was the forerunner of the pole-trolley that has seemed to solve the problem of cheap electric roads for local traffic and suburban lines.

It was just after 1881, the year of the first general Electric Congress in Paris that the electrical standard units began to come into use all over the world. The system is based on the metric system, and is built up out of the metrical units the centimetre, the gramme,

and the second (of time). Hence it is called by the initials of these words — the "C. G. S. System." The shortest statement of the system is by means of a table. These are the C. G. S. units:[1]

The Unit of Force=propels one Gramme one Centimetre in one Second=1 dyne.

Work unit=1 dyne × 1 centimetre=1 erg.

Quantity unit=quantity conveyed by 1 dyne in one second (=10 coulombs). But these are inconveniently small for practical work, and therefore they have been replaced by practical units derived from them, as follows:

The ampère=$\frac{1}{10}$ the current strength unit in the C. G. S. system.

The volt=100,000,000 (sometimes written 10^8 meaning 1 and 8 ciphers) C. G. S. units, is the unit of electro motive force.

The ohm=the resistance of a conductor that will produce one ampère from one volt=10^9 (or 1,000,000,000 C. G. S. units).

The coulomb=the quantity carried by unit current, one ampère in one second.

Philip Atkinson in "Electricity for Everybody" gives comparisons by which the general reader may get some definite idea of these practical units — the only ones he is likely to meet with except in special investigation. The volt, he explains, is very nearly (.926) the electric pressure of one Daniell battery cell; and it must be remembered that the pressure is the

[1] For a *full* table, see "Standard Dictionary" under "*unit.*" An excellent statement and explanation of these units will also be found in "The Story of Electricity," by John Munro, published by Macmillan & Co.

same whatever the size. The *ohm* is about the resistance of an ordinary thermometer column of quicksilver increased to nearly 41¾ inches in length at 32° Fahrenheit temperature — freezing point. Or, we may quote from Professor Houston, it is equal to the resistance of one foot thin (40 American gauge) copper wire, or two miles of ordinary trolley wire — as we have before said. And the *ampère* is the current a Daniell cell would send through such a column. A *coulomb* would be the amount of electricity flowing along such a column from the Daniell cell in one second.

For the sake of completeness the following units are added from Alglave and Boulard's "The Electric Light." They are merely defined, not fully explained, as they are found in modern dictionaries:

Farad (from "Faraday") is the unit of *capacity*= $\frac{1}{1000000000}$ C. G. S. unit of capacity. The Microfarad is one millionth of a Farad.

Calorie (from "Caloric"), unit of *heat*=4.2×10,-000,000 ergs.

Joule (from the name), unit of *work*=10,000,000 ergs.

Watt (from the name), unit of *power*=10,000,000 ergs a second.

746 Watts=one (English) horse-power.

735.75 Watts=one (French) force de cheval.[1]

[1] One centimetre=.3937 inch.

One gramme=15.432 grains=1 fifth the weight of a five-cent nickel. Hence to move a nickel $\frac{1}{3}$ of an inch requires 5 dynes, against no resistance. To lift it is to act against gravity, which is about 981 dynes (since it moves a falling nickel with an *increased* velocity every second sufficient to carry it through 981 centimetres). Therefore 5 (grammes)×981(dynes)=the number of Ergs done in lifting a nickel a little over a third of an inch, or 4,905 Ergs. A Watt ($\frac{1}{745}$ horse-power) is equal to 10,000,000 Ergs.

To give another simple table, derived from the relation of the commoner units:

E. M. F.=Volt=Ampère×Ohm.

Resistance=Ohm=Volt÷Ampere.

Current=Ampère=Volt÷Ohm.

Quantity=Coulomb=Ampère×second.

Capacity=Farad=Coulomb÷Volt.

The farad is the capacity of a conductor capable of holding one coulomb at one volt potential.

Work=Watt=Volt×Ampere=$\frac{1}{746}$ horse-power, or 44.25 foot-pounds a minute.

Kilowatt=1,000 watts=nearly 1⅓ horse-power.

The prefix Kilo is used in the same way to multiply other quantities, as Kilerg=1,000 ergs; Kilo-ampère; and so on. Other units exist and find special use, but all are derived from some of those mentioned above. In practical handbooks tables are given showing the electrical qualities of wire and so on. Thus we find that wire of pure copper about 2½ millimeters in diameter (2.588) gives one ohm resistance when 1,000 feet long, and may be safely used with current of about 20–40 ampères, depending on whether it is in open or "concealed" work; and that hard drawn copper wire guage No. 10, B. & S., weighs 104 pounds to the mile and offers 8.7 Ohms resistance per mile. These figures are taken from a pocket "Compend of Electricity," by J. A. Beaton, published in Chicago in 1901.

Enough — perhaps more than enough — has been said to show how the science of electricity has created a new set of words for the languages of the world, though fortunately by international comity, these words are alike in all languages. One might fancy

electricians to converse in them to a certain extent, though ignorant of each other's native tongues. Thus one might point to a high hill and write on a pad, "100,000 Ohms!" to indicate it would be difficult to climb, while the other might reply by pointing to his sturdy legs as capable of a "Kilowatt."

But, seriously, it is of enormous value to the world's progress that scientists should be able to make their work easily intelligible to the whole world by a common system of units, and these also carry with them similar names for electrical instruments and similar diagrams and symbols to explain the action of electrical apparatus.

CHAPTER XX

ELECTRICITY APPLIED IN ALL FIELDS

In order to proceed to the year 1885 only a few items of progress need be mentioned. An experimental telephone line was built from New York to Boston, and proved so successful that within three years it was equipped and opened to the public.

A second congress of electricians was held in Paris in 1884, confirmed the standard units, and adopted the Farad, possibly at the suggestion of Sir Werner Siemens who named the "Watt." There was added to the methods of conveying current to a railway motor the use of an underground system, in which the conductor of the current was in a conduit. Thus in 1883 there was more than a beginning of practical electric railways, for Leo Daft of New Jersey had operated a small railroad between Saratoga and Mount McGregor two years before that; and in 1885 there was a suburban line two miles long from Baltimore to Hampden, also designed and constructed by the same electrician. In the year 1886 the railway operated on the system of Charles J. VanDepoele was opened in Scranton, Pennsylvania, and by 1888 there were "twenty-three lines having a total length of about a hundred miles," says Franklin L. Pope in "Electricity in Daily Life."

Between 1885 and 1890 there was similar progress in other electrical industries. Elihu Thompson made

use of the intense heat of the electric-arc for welding metals, his earliest patent being dated August 10, 1886. He used a current of small voltage but high amperage, and by a number of inventions adapted his process to all kinds of work, using transformers to control the current, clamps to fasten the work together until welded, and so on. The process is complicated, but contains no really new electrical principle, being merely a combination of ingenious methods of applying the current in the right condition and shutting it off when the work is done. The process succeeds readily with metals that do not weld in ordinary methods, and can be applied — as in welding together the already laid rails of a railway — almost anywhere.

Here again is a whole new art that would require a volume if not a library to itself, for it includes electric welding, forging, casting, and soldering. As has been well said in "Flame, Electricity and the Camera," the control of the electric current has not *added* to man's powers so much as *multiplied* them. "As we trace a few of the unending interlacements of electrical science and art with other sciences and arts," says the author, George Iles, "and study their mutually stimulating effects, we shall be reminded of a series of permutations, where the latest of the factors, because latest, multiplies all prior factors in an unexampled degree. . . . This principle stands forth in that latest accession to skill and interpretation which has been ushered forth by Franklin and Volta, Faraday and Henry."

So, as it is impossible to write the history of all arts at once, we cannot tell how all of them have been recreated by the power to carry electricity to any work

and then to cause it to do work in the form most convenient — whether as electric vibration, chemical action, heat, power or light; whether as tool, detector, regulator, or destroyer.

We have given somewhat full explanations of the earlier electric inventions, especially of such as enable the reader to understand the principles that underlie later applications. But the increasing complexity and broadened field of modern electricity is multiplied in geometrical ratio. Each invention gives rise to dozens more, and we are therefore compelled by our limited space and by our purpose, to pass by with only a hint as to their method of working countless minor devices by which inventors have brought electricity into use to serve mankind.

Still we believe that with an understanding of the principles already explained herein, the reader will be able to see the general idea of modern electric devices, and by careful examination of the current path, as the electro motive force traverses its conductors, coils, and magnets, and is changed to light, heat, or mechanical motion, to see why the effects are produced.

In the early days a few popular lectures would put any one in possession of the essential facts known about electricity. Now the training of an electrician requires not only a liberal education from the beginning, but daily study to keep up with the progress of each specialty. A prominent electrician is said to have remarked recently that if he simply kept himself informed as to the constant additions to his science, he could find time for nothing else. Besides, it is not necessary to carry in one's head a great mass of facts that are instantly available through reference-books

whenever needed. H. G. Wells remarks with equal wisdom and wit that most facts "keep better in the books than in the brain." The specialist will have his own library, the occasional student may consult the public libraries, and every one should have at hand at least the small hand-books that can be bought for half a dollar or less. These will be available at any moment, and in general they are very good and very helpful in understanding such electrical terms and phrases, or such new inventions as are part of the news of the day.

After reading even so general a little book as this is, no one will be so foolish as to look upon electricity as a magical creation of power. Like all the forces with which man deals, electricity must be paid for either in work or in ingenuity of application and control. If we make a dynamo to run a motor, we must supply energy to the dynamo by steam, wind, water, or chemical power. Even a waterfall, power in a most usable form, must be harnessed and directed in order to change its motion into that rotary form we find most useful; and as yet there is no way of arriving directly at any great reservoir of steady electrical energy. That may some day be found in the light waves that come from the sun, and on Clerk Maxwell's theory that light and electric waves are different manifestations of the same energy, the taking of electricity directly from sunlight may be looked upon as possible. But meanwhile electricity is used as a *form* of power, and the power must be taken from natural forces before it can be electrically applied.

An interesting story of the great philosopher Faraday illustrates not only his wisdom but his com-

mon sense. It is said that an inventor exhibited an electric machine to a number of capitalists and experts, including Faraday, and made great claims as to its commercial value. Then he started it, and caused a large fly-wheel to revolve rapidly while his spectators gazed. Faraday picked up a broom, and pressed the handle against the edge of the wheel. The wheel slowed down, "hesitated," and came to rest. Faraday left the room in silence, and very likely the capitalists followed.

He knew that electricity did not create power, and in those days of voltaic cells, the electric machine was not what it has since become.

But it has been truly objected by a thoughtful critic that Faraday did not at all appreciate the wonderful possibilities in the device he was viewing. He — great genius as he was — did not see that a change in certain *conditions* was to make the electric motor a commercial possibility.

To return to our story, the year 1887 was notable not only for practical progress but for advances in theoretical study that were the foundation of great improvements later. The telephone was rapidly being extended as its instruments were improved and as the public became educated in its convenience; and the electric motors and electric light were also firmly established as every-day matters. But a new name is met with, in the electrical field, in connection with the theory of dynamos and motors, and of electric wave-motion — that of Nikola Tesla. In 1882 he made an invention which has become known as a "rotating magnetic field," but Professor Houston declares that some portion of the credit must (as usual) be ascribed

to other workers in the same field — of whom he names especially Professor Galileo Ferraris. Yet to Tesla the chief credit undoubtedly belongs. He was born in 1857, a Serbian, educated abroad, and becoming an engineer and inventor worked for some time in the Edison laboratory. He subsequently established a laboratory of his own, and became the Electrician of the Tesla Electric Light Company of New York.

His inventions relate to electric lighting, power, and transformation; but the most important of all is a form of electric dynamo and motor known as the multiphase or polyphase. It has neither commutator nor brushes. Though ridiculed when he proposed to eliminate these, by 1888 he had made multiphase motors equal to any of the old types in efficiency. These motors have later been called "induction motors," since they operate by inducing currents from the field, or "stator," in the armature ring, or "rotor."

Consider a ring-armature wound with a closed spiral coil of wire all in the same direction. Now let two alternating currents be supplied and withdrawn at four equi-distant points — say, North and South, East and West — so that when one is at its highest potency the other is at its lowest. That is, one enters at N, leaves at S; the other enters at E, leaves at W. Imagine the ring fixed, and a magnetic needle placed in the centre, and free to rotate. Then as the first current enters at N, the needle is moved to turn across it; but this current is now losing power, and the next current influences the needle to turn further round to cross that current (by Oersted's deflection principle). It moves still more, and is thus brought into the influence of the first current *reversed*, turns,

and comes within the field of the second current reversed and so on.

In short, all around the circle, the current is supplied in such direction and force as will keep the needle turning in one direction. This will be easy to understand if we suppose four electricians to be standing at the four quarters of the ring with positive and negative live wires, and at each quarter to apply the right current to keep the needle deflecting in one direction — that is revolving. But what the electricians could do by hand is done with enormous speed mechanically by the motor-mechanism. So the needle keeps on turning.

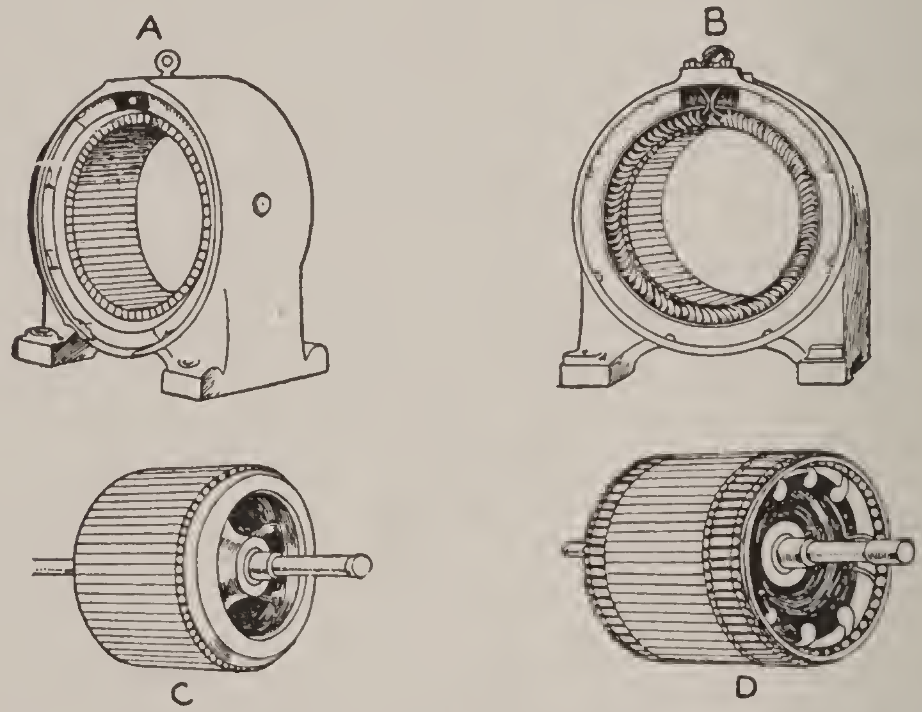
It is therefore a motor. But in the actual machine instead of a needle, another ring free to revolve is put inside the first or "stator" ring. And this second or "rotor" ring is so wound with a number of closed coils of wire that when electrified by induction currents it revolves as the magnet would — but at enormous speed.

Such is the polyphase motor with *two* currents, called the diphase motor. But the same principle can be applied to smaller parts of the stator ring than a quarter, and so we have the triphase or multiphase motors — in which currents enter the ring at many points but always in the direction that will keep the rotor ring turning.

It will be seen that, given the wires conducting the necessary currents, only two parts are necessary in these motors and dynamos — the rotor ring, and the stator ring, each properly wound. In fact it seems as if simplicity could go no further — unless we should be able to make electric fields without any conductors

at all — simply currents whirling in the ether! And these motors can be placed anywhere that a pulley of the same size would go — at the top of a pole, against a ceiling or wall, or in a pit. Used as dynamos to give electric current, they may be placed on a shaft, like any wheel — and are thus especially fitted to be used with the turbine water-wheel, as at Niagara.

They do need, however, a starter when of large



THE POLYPHASE INDUCTION MOTOR (WESTINGHOUSE TYPE).

A—The housing and primary, or *stator* unwound. B—The primary, or stator complete. C—Core of secondary, or *rotor* unwound. D—The secondary, or rotor, complete.

size; but this means only the momentary putting of a transformer in the circuit by means of a switch, that will supply a smaller voltage for a while. The reason they need to be started will be evident on reflecting that the currents are applied successively, and if all were turned on at once, the moment lost in overcoming the rotor's inertia would cause simultaneous instead of successive action of the currents for that

moment. It would be like a steam engine when on a "dead centre."

The polyphase machines have no brushes to waste power in sparks, no commutators to be injured, no connections where arcs can be formed to heat or burn the apparatus. They are almost ideal machines, needing only a ready means of regulating their speed. And this has already been furnished in more or less perfect form by devices for regulating the currents supplied to them.

Of course the direct current motors, the alternating current motors, and the polyphase motors will each eventually find the use for which it is best adopted. For it is universally true that very few machines are entirely superseded by later inventions, being only replaced for particular uses.

It will be remembered that in 1845 Faraday had observed that polarized light was affected by magnetism — that the rays were turned about an axis, or rotated, by a magnet. Twenty years later the connection between light and magnetism or electricity was expressly asserted by Clerk Maxwell, who found that the speed of light waves and that of electric waves were the same.

Twenty-two years later, in 1887, another proof was found that the light energy and electric energy were identical or closely connected. By means of a device for enormously increasing the reversings of an electric current, the investigator Hertz produced certain waves in the ether which, though caused by electricity, could be reflected by a mirror, could be separated into their simple waves (or their elements, much as light is separated by a prism) and would even

cast shadows. As Mr. Bowker says in his article, "Electricity," published in *Harper's Magazine*, "In short, though produced by electricity, they acted like light; which seemed to confirm by experiment the theory of Maxwell."

Heinrich Hertz was born in 1857 at Hamburg, and became a professor at Karlsruhe and afterward at Bonn, where he died in 1894. Though he is credited with the discovery of the identity of light and electric waves, it should rather be said that by experiment he furnished the proof that certain electric waves could be made to follow the same laws as light waves. It will be remembered also that in speaking of Professor Henry's discoveries we noted that he discovered the discharge from a Leyden jar to be an oscillation, or a to and fro movement in opposite directions of the ether. Clerk Maxwell had shown that if these oscillations could be produced at certain given rates these waves could be made to act like the waves of light, sound and heat.

As stated by Sir Oliver Lodge, Maxwell's discoveries amounted to a proof, or almost a proof, that light is in fact an electro-magnetic disturbance. There are to-day so many proofs that the two forms of energy are identical that we may even assert the fact and add that every day brings new evidence to complete the proof.

We shall not attempt to go very deeply into the question of ether waves. We must take for granted the conclusions of the greatest experimenters that there exists throughout space and extending throughout the substance of all kinds of matter something known as the "ether," which is described as a medium

without weight infinitely, more subtle than air, capable of receiving and transmitting vibrations at different rates. These vibrations, known as ether waves, vary in direction of vibration, in speed, and in extent. According to their extent, their speed and their direction, they produce effects which give rise to what we know as heat, light, electricity and magnetism. They are also produced by all forms of mechanical action, and in fact are believed to be caused by every form of motion and every manifestation of energy.

Sir Oliver Lodge in England a few years before Hertz's experiments began had discovered that by rapidly charging and discharging a Leyden jar in the neighborhood of another similar jar, but without any conductor between them, he was able to charge the second jar electrically. But this effect was produced only between jars that were so far alike as to be considered in electrical tune with one another. In order to bring them to the same electrical harmony, Lodge devised a method of changing the dimensions of the second until it responded to the first, just as in a musical instrument a string may be tuned so as to respond to another.

A very similar method of procedure was adopted by Hertz, who devised an effective apparatus for setting up and for receiving oscillations. Before describing the nature of his devices it will be well to see just what place in the art of electricity they occupy by making a sort of tabulation showing the general progress in knowledge of electricity.

The first discovery made by man was that certain bodies were in a state known as electrified, that is, they were in a state that would under proper condi-

tions attract or repel certain substances. This state was that of electricity at rest, or static electricity. Next it was found that by means of supplying paths or conductors the electrical energy could be conveyed along the conductors to other things. This was electricity moving, or "current" electricity. The third step was to detect in magnets electricity constantly moving in a circular path, or "rotating" electricity. Man learned to understand, and then to produce at will, and to some extent to govern, these three states.

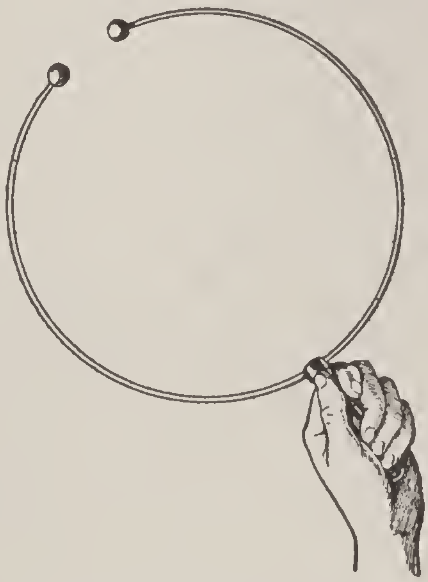
The next step was the discovery of still a fourth state where electricity, or the ether wave-motion, was in vibration or radiation; that is to say, the disturbances in the ether appeared in the form of to-and-fro motion and were transmitted through space without any conductor.

This classification of the gradual steps of electrical science is quoted from Sir Oliver Lodge by Charles R. Gibson in his "Romance of Electricity," and will enable us to understand the great importance of the step forward made by Faraday's discovery of the electric action on light waves, by Maxwell's wonderful theory of their action and their identity with light waves, and Lodge's and Heinrich Hertz's invention of practical means for producing electric waves, or electricity in this fourth state.

Hertz's apparatus consisted of a large induction coil prepared so as to produce sparks; that is, the ends of the secondary coil, or that in which the current is induced, were connected to brass balls or knobs movable so as to be placed at different distances from one another. These knobs can be adjusted at just the right distances apart so that the induced current is

strong enough to send a spark across from one to the other, that is, to overcome the resistance of the air gap between them.

An induction coil and a Leyden jar, as has been said, are electrically similar contrivances, and the discharge from a coil, like that from a jar, is an oscillation setting up waves in the ether, as Henry discovered in 1842. It was Hertz's theory that these waves, if they could be made to strike upon a conductor of the right sort, should set up waves around it. He



HERTZ'S DETECTOR

bent a copper wire into a circle of about sixteen inches diameter, but instead of joining the ends put two copper balls on them, so that if the current, or succession of waves, were to pass along the wire it might be visible as a spark when it jumped from one ball to the other. This he named the "electric eye" or "detector." The reader will remember that the object of these round balls is to prevent the soundless discharge that occurs from points, (as discovered by Franklin),

and by causing a spark to make the electric action visible in light.

When the induction coil was excited so as to produce sparks, this wire was held a few feet away by means of an insulated handle. The first experiment produced sparks in the air cap at the ends of the ring, but these were so minute that they could be observed only in a darkened room.

The distance at which this Hertz detector acted was not more than a dozen feet, and yet in this experiment lay the principle that has created wireless telegraphy.

The next step necessary to make Hertz's apparatus practically useful was to apply a discovery that has already been noted, namely, the fact that iron filings, although they act as a very poor conductor when in a state of loose contact, joined one another (because magnetized) to some extent as soon as they were brought under electrical influence, and thereby formed a conducting path.

It will be remembered that Morse, in order to extend the action of his telegraph, invented the relay in which he used a weak current to move a small bar that closed the circuit of a stronger current. The same idea was applied by Professor Branly to causing weak Hertizan waves to set in action a strong current. He had only to fill a small glass tube with iron filings, not packed closely, and to place this tube by means of a wire at each end in an electric circuit.

The discovery of the coherer, as this tube of iron filings was called, was the result of a number of researches and experiments beginning as far back as 1850. These experiments had shown that the passing of an electric spark between two conductors placed

closely together seemed to make a sort of permanent bridge between them. This was studied at first in relation to certain devices known as lightning arresters, which consist of a gap left in an electric circuit wide enough not to be passed over by the ordinary charge but not too wide to be crossed when a strong current such as a lightning stroke enters the circuit.

Sir Oliver Lodge, in 1889, modified the usual form of lightning arrester — which was two saw-tooth edged plates opposite one another but not touching — replacing them with two metal balls. He observed that the spark having once passed between these balls, which must have been almost in contact, the current continued to pass from one to the other. These devices for detecting electric waves were used for some time before they were adapted to the sending of signals, and the Branly coherer seems to have been employed mainly for detecting electric waves, whether given by an apparatus or existing in the air. But the commercial use of the Hertzian waves in telegraphy was not to come until after some years.

We shall obtain an excellent idea of the extent to which electricity had entered the commercial world by examining some of the statistics given to show electrical progress by *The World Almanac* for 1891. The amount of money invested in electrical industries in the United States at the end of 1890 was computed to be six hundred millions of dollars, one-fifth of this in telegraphy; eighty millions, more than one-eighth, in telephones, fully one-half, or three hundred millions, in electric-light and power companies, and the rest in electrical supply companies. Of electric roads there were a hundred and thirteen in operation, forty-five

more being constructed. The subscribers to telephone exchanges numbered one hundred and eighty-five thousand, using over four hundred million connections a year. The number of incandescent lights was over eight hundred thousand, and of arc-lights over twenty-five thousand.

Conversation by telephone was carried on over a distance of seven hundred and fifty miles; the fastest time made by electric railways was a mile a minute, twenty miles an hour was a usual speed in street railways. The most powerful motor then in use was of seventy-five horse-power.

The novelty of that day, though it had been in use for a year or two on one railway, was telegraphing from a moving train. This apparent marvel was accomplished without great difficulty by the use of an induced current. The means of procedure had been first suggested as far back as 1853, but did not come into practical use until about 1887. The method of telegraphing is as follows: Inside any car is carried an induction coil that can be thrown into vibration by a make-and-break contact, like the Ruhmkorff coil. When this is acting it induces a current in its secondary coil. This current is connected to the tin roof of the car, which also is thus electrified by an alternating current, first positive, then negative. The making and breaking and change in force in this current cause an induced current to be set up in a conducting wire stretched above and parallel to the track, but of course not in contact with the car. A telegraph key of the ordinary sort is now used to start or stop the induction coil in the car. When it is closed the alternating currents are produced, and when open

they cease. A long closing of the key makes a dash, a short closing a dot, an opening of the key makes a space, and a receiving instrument of the ordinary kind being connected at any station with the wire beside the track can receive signals precisely as if it were in an ordinary telegraph circuit. A telephone receiver is,

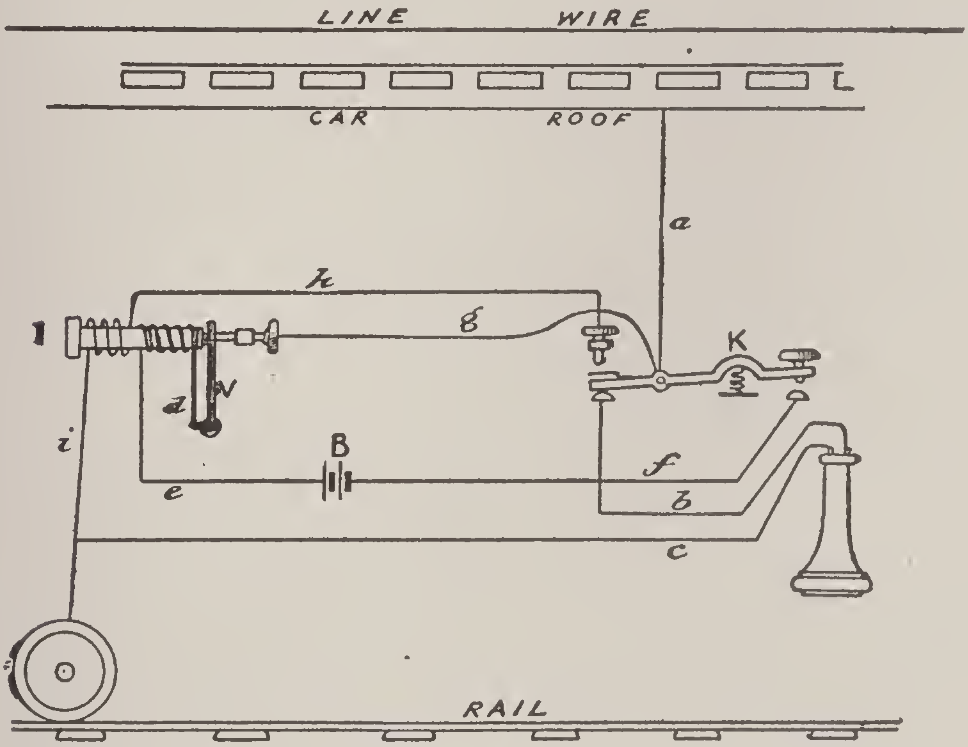


DIAGRAM SHOWING METHOD OF TELEGRAPHING BY INDUCTION FROM MOVING TRAIN

In receiving messages electric impulses from the vibrator of an induction coil induce currents through the car roof, by wire *a*, key K, telephone wires *b c*, car wheel and ground. In sending messages closing key K works induction coil I, and vibrator V, through battery B, and primary circuit *d e f g*, and the secondary circuit *a h i*, charging the metallic car roof, influences by induction the line wire and telephone at receiving point.

however, used as more convenient, and the signals received by hearing, ordinarily.

The transmitting of signals to the car is only a reversal of this process, the induction coil in the station being connected with the wire stretched parallel to the railway lines. Currents set up in this wire induce the currents in the car roof, thereby affecting a telephone-

receiver attached to the roof by a wire and used in the car as before.

It will be seen that for a short distance this is really a form of wireless telegraphy, since the waves between car and line go through space without a conductor.

The foregoing description has been based upon an article in *Scribner's Magazine* for 1889, and the concluding paragraphs of this article plainly foreshadow the possible extension of wireless telegraphy to something like the system we know to-day, though the author, Charles M. Buckingham, seems at that time to have thought about half a mile the limit within which such communication was then possible. It is true, however, that he speaks of certain earlier experiments wherein parallel wires were used to induce currents in one another, as permitting communication for a distance of from one and a quarter to six miles, from the Isle of Wight to the English coast in Hampshire.

It will be seen that the missing element in extending the operation of this system was the relay, namely, some device that would detect faint electric waves and use them to set in action a stronger current. This was to be supplied, as we know, a few years later.

Also, from *The World Almanac* of that year, we learn that there were about nine hundred and fifty submarine cables then in use, covering a distance of about a hundred and eighty thousand miles.

In 1890 the most important events were the general adoption of electric light in a number of great foreign cities, notably in Rome, Paris, Milan, Tours and Marseilles, and the beginning at Niagara Falls of the work destined to convert the energy afforded by that

cataract into electric currents for transmission to a distance.

The progress in electric railways continued in increasing ratio. The earlier motors had been most uncertain in their operation, not economical nor particularly well adapted to car-traction. The causes of failure were various, but among them may be mentioned the burning out of the copper brushes used upon the armatures, causing a very great expense for their continual replacement, the uncertainty of the methods of control adopted for regulating the high power transmitted to the motors, and, generally, the inferior nature of the motors themselves to those devised later.

A very complete and exhaustive account of the various experiments made in securing the right conditions for railway motors and their application will be found in two papers written by Frank J. Sprague, a noted inventor in this line, for *The Century Magazine*, July and August, 1905. It adds to the interest of these articles that the author is fairly to be credited with perhaps the larger part of the inventions that have given us the electric-railway systems existing throughout the country to-day in the inter-urban trolley roads. Those who will give themselves the pleasure of reading these articles will find in them another illustration of what should be an accepted axiom, "The way of the inventor is hard," and will appreciate that between the theory formed by the cleverest inventor in his laboratory and the application of the same theory to the actual conditions met with outdoors there is a wide and howling wilderness filled with ravenous facts hardly less difficult to over-

come than the array of dragons and wicked enchanters that in the fairy stories are conjured up between the adventurous prince and the imprisoned princess.

From the earliest experimental car that upon a specially built track a few hundred feet long in Berlin conveyed a dozen or two passengers, to the enormous trains that endlessly follow one another along the tracks of the New York Subway, packed to overflowing night and morning, there was a hill of difficulty only to be surmounted by skill, patience, and marvelous ingenuity, and the story of the surmounting of this hill is well told in the articles mentioned. Another good reason for referring to these articles is the fine series of illustrations showing photographs of electric railways from the crudest beginning to the modern forms.

One hesitates to chronicle as an advance in civilization the adoption of the alternating current to the killing of criminals. In August of 1890 took place the first electrical execution at Albany. The use of the current for this purpose was advised after due consideration by an eminent board, but it has been fairly said in criticism that the only excuse made for this form of execution is based upon a pure assumption. Because death from the electric current is apparently sudden, we assume that it is more merciful than older methods, but despite expert opinions we cannot *know* this; and the only reason for being glad of the adoption of this method of execution lies in the fact that the popular interest in its novelty led to the publication of accounts of the first execution in such detail as to bring about a public sentiment demanding that this publicity should be stopped. A law was passed for-

THE FIRST ELECTRIC ENGINE TO LEAVE THE GRAND CENTRAL STATION

By courtesy of The Scientific American.

bidding more than the publication of the fact that the criminal had been put to death. It is sincerely to be hoped that before many years the death penalty itself will be abolished.

The year 1891, besides further study of the Hertzian waves and the patenting of the Berliner and Edison telephone transmitters, was notable for the successful transmission of electrical power in Germany, something under eighty horse-power being transmitted from falls of the River Neckar. London in this year also followed the example of the Continental cities already mentioned in setting up permanent electric lights, the first in that city being in Victoria Street. A step tending to make the electrical units better known among experimenters was the printing of the report of the Electrical Standards Committee, an excellent preparation for the fuller discussion that was to take place at the Chicago World's Fair two years later.

By 1892 the amount invested in electrical work in the United States had increased by another hundred million dollars. The number of telephone connections used also had increased by a hundred millions within two years, showing the enormously rapid spread of the telephone as a means of transacting business. The mileage of electric roads had reached about four thousand, and the use of the underground conduit for conveying the current was rapidly increasing.

On October 18, 1892, Professor Bell sent the first message by telephone from New York to Chicago. In speaking of this accomplishment an article in *Scribner's* of the present year (1906) asks, "What greater marvel is recorded in 'The Arabian Nights'?"

Another event of the same year, 1901, the impor-

tance of which was hardly then appreciated, was the exhibition by Nikola Tesla of his alternating current motor at the Royal Institution of London. This is a milestone from which to estimate the growth of the multiphase motors which began soon after to compete seriously with the direct-current motors then generally in use.

Another discovery, the development of which even up to our own time has been far from exhausting its possibilities, was that of Arons, who showed that mercury vapor enclosed in a vacuum tube emitted light-waves, a discovery later developed practically by Cooper–Hewitt of New York in his well-known mercurial vapor light. As Arons does not seem to have used the discovery practically, we shall postpone an account of its nature until we consider the Cooper-Hewitt lamps.

In 1893, the year of the World's Fair at Chicago, there was at that fair a meeting of a great electrical congress, and the exhibits in the electrical building gave a very good summary of the general state of electric science at that time.

From an article in *The Cosmopolitan* describing the wonders of the World's Fair at Chicago, we may get an idea of the awakening of the world to the achievements already brought about by the applications of electricity and to the possibilities promised. Rightly enough, the author, Murat Halstead, gives first place in describing the wonders of the fair to the marvelous effects of the electric lighting, which must have impressed every visitor with the knowledge that mankind had really doubled its hours of light. The reign of night had been overthrown. It is hard for us to

realize what it means to mankind to have secured the ability to make use of the hours of darkness precisely as if the sun was shining, to convert a vast area into a pleasure-ground available by night as well as by day.

He next speaks of the electric launches, so impressive in their swift and silent power; the railway cars that were moving by the same magical, soundless, and resistless force. Rightly, too, he speaks of the telephones that enabled one to "talk to friends a thousand miles away and to enjoy the familiar charm of their voices and the magnetism of their presence." All these marvels were due, he says, to "the same mighty, subtle, delicate, formidable agency and mystery that permeates the atmosphere which compasses the universe." And the great wonders he describes are actuated by "but one breath of the all-embracing vital air, one sparkle of the surf that is the boundary of oceans, the great deeps beyond, unfathomable, but one may believe not unsearchable, not past finding out, but holding their treasures for the swift unfolding of the slow centuries."

While we are discussing the wonders of electricity with a mind mainly bent upon the method of their working we may well be glad to give a moment to such poetic sentences as these, in order that we may not forget the spiritual grandeur of the problems with which we are dealing.

Nothing better shows the universal applications of electricity than even a brief list of its uses at the World's Fair. It was electricity that turned its night into day; that cast upon notable objects the unparalleled emphasis of the searchlight; that by telephone

connected the whole nervous system of the administration into a single organism; that enabled the police to supervise constantly every part of the grounds, that was ready at any moment's notice to give the alarm of fire; that turned the great wheels driving the marvels of mechanism; that carried visitors from point to point and enabled them to fly as if upon a magic carpet from one end of the great fair to the other.

One might go further and say that the fair itself was built by electricity, which sawed timbers, hoisted weights, ran the pumps, painted the buildings, lighted the grounds for night work.

In addition to the uses mentioned, the electric railways were guarded by a block system and provided with automatic braking devices to stop the trains in case of accident, and both these used electricity as their animating power. Another safety system used at the fair consisted of electrically lighted buoys pointing out the dangers of the shore from the Chicago River to the fair grounds.

And to view all these applications of the new power the distinguished electricians of the world gathered from all civilized nations to receive at Chicago a widened view of the domain and of the possibilities commanded by their science.

These men gathered in a congress similar to those which had before met at Paris and did rightful honor to the memory of Professor Joseph Henry by giving his name to a new unit, the unit of inductance. They also added to the value of the standards in use by declaring a set of practical international units which have since been adopted throughout the world.

Apart from these general advances in the science, the more notable achievement of the year comprehended a very great improvement in the storage battery, tending to make it more economical and more lasting; the discovery that by means of an electric arc formed under water metals could be melted by a heat so intense and so rapidly applied as to heat neither the water in which the contact is made nor any portion of the metal except that touched by the arc. It was suggested at once that this made it possible to temper small portions of steel tools where desired, without the need of hardening any more of the material.

A fact that is perhaps more curious than significant was the inclusion of a whole electric equipment upon Nansen's ship for arctic discovery, *The Fram.*

Of much greater importance were two notable advances in industry brought about by the use of the enormous heat of the electric arc. Means to apply this to various substances were devised by Professor Moissan of Paris, Siemens, and other investigators.

The electric furnace may be divided into main types: those which produce the heat between two poles of a circuit (between which is an air-gap or space filled with some gaseous substance), producing their heat in the electric arc; and those which produce their heat in a poor or a narrow conductor connecting the poles, thus slowing the vibrations and changing some of the electricity to heat.

The first form of furnace consists essentially of a box made of chalk or of fire-clay with conductors, usually of carbon, passing through its walls. Within this box is placed the little crucible, which may be of carbon, magnesia, or other substance not easily des-

troyed by heat. At times a little window of ruby glass is inserted, so that the work of the arc may be watched from the outside. There are also tubes arranged through the walls of the box so that various gases may be allowed to enter if combustion is to be set up in some other gas instead of in air.

The form of electric furnace known as the resistance or incandescent furnace, differs from the arc-furnace only in connecting the poles by means of a conductor of high resistance. The passage of the electric current heats this conductor, and the heat so generated is applied to any substance that may be piled over and around it, giving a less intense, but more controllable, heat where such is desired.

If the poor conductor is a liquid solution we have still another class of furnace to consider.

There is a very great variety of these electric furnaces, but their heat always comes as in those already spoken of, from causing a current to pass from a good to a poor conductor. If the current has to pass an air space, an electric arc is formed and great heat is given out. If the current has to pass through a smaller (thinner) conductor, this becomes heated and may become incandescent. If the current passes through a liquid of high resistance (poor conducting power) the liquid likewise becomes hot. This gives the three great classes of furnaces: Arc furnaces, incandescent furnaces, electrolytic furnaces. But all or any of these principles may be used in a single furnace. Then, too, there are cases when it is necessary to use an induced current (instead of a primary current) in the furnace, and this gives us an induction furnace.

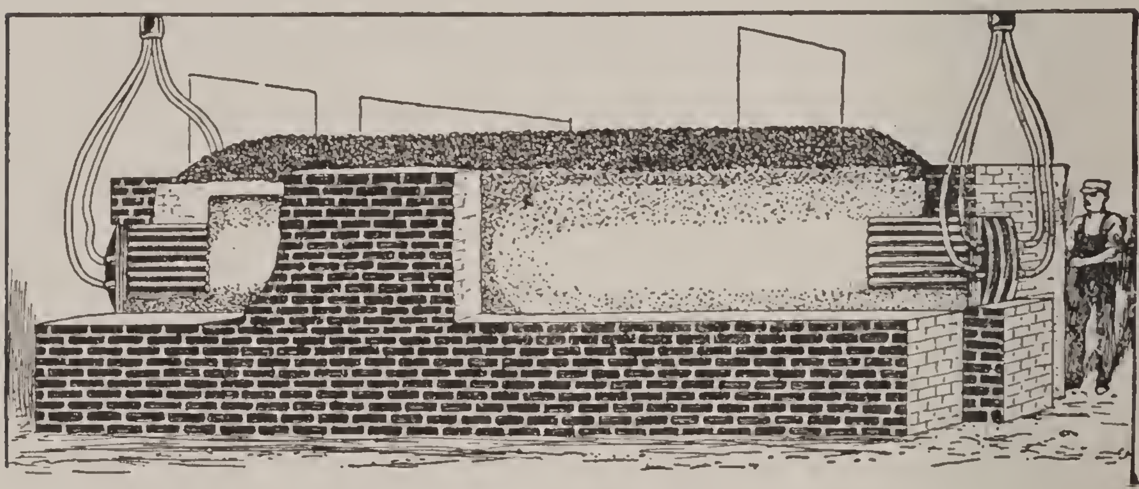
We must be satisfied with the general principles here, since the applications are as numerous as the needs for various forms of heating. The uses of electricity as a heating agent cover an enormous field, extending from the use of a hot wire in medical practice to the working of great quantities of metal in enormous factories ; but all depend on the heating of a conductor through its resistance to the passing of the current.

To give only a single example, by passing a current through coils of fine wire in a street car, the wires are heated, and the car is warmed.

Another device should be explained as it has other applications besides its use in an electric furnace. In the early days of study of the electric art it was discovered that the arc itself acted as any current would act in the presence of a magnet — that is, it was deflected from the magnet's lines of force, according to the usual law of repulsion of currents. This property of magnets has been used even to deflect an arc enough to blow it out ! In the electric furnace this property is used to direct, or deflect, the arc toward the place where it is to be applied. By means of the enormous heat, the greatest in the command of man, such refractory substances as platinum, carbon, and chromium can be readily melted, and thus new commercial substances unattainable in quantity in any other way have been really created.

Among these we may mention carborundum and carbide of calcium, the second being the mineral from which by the mere application of water acetylene gas is obtained. It is true that acetylene had been known since 1836 and had been prepared in 1862, but, as the

"Encyclopedia Americana" says, "both it and the carbide of calcium were laboratory curios until about 1893, when the electric arc acting upon a mixture of lime and carbon produced the carbide in large quantities." Carborundum (carbon and silicon) is made by heating together in an electric furnace sand and carbon. Discovered in 1891 by E. G. Acheson, the annual production of factories at Niagara Falls is now about five thousand tons. This substance is the hardest known excepting the diamond, and resists heat so completely that the inventor declares a layer



A CARBORUNDUM FURNACE

This material, carborundum or carbide of silicon, is electrically produced by passing a current through a core of coke, surrounded by a mixture of carbon, sand, sawdust and common salt. It is commercially employed as an abrosive, for grinding wheels and as a substitute for emery, and is almost as hard as the diamond.

one-twelfth of an inch thick will protect bricks against the highest temperature ever produced in ordinary work.

To the credit of the electric furnace also must be put down the cheapening of aluminium, a metal the importance of which it is impossible to consider too seriously. Many great engineers, Nikola Tesla, for example, believe that the present age of iron will in-

evitably be succeeded by the age of aluminium. We cannot here give the facts justifying the opinion.

Though Sir Humphrey Davy attempted to obtain the metal, aluminium, early in the nineteenth century, it was first separated in 1827 by the chemist Wöhler. This metal is, next to oxygen and silica, the chief component of the earth's surface. It is even more abundant than iron. The metal was first obtained in fair quantity by Professor Deville, of Paris, who as a sign of his success presented to the infant Prince Imperial of France, son of Napoleon III, a baby rattle made of this hitherto hardly known substance. By 1860 aluminium was being made for eight dollars a pound and sold for twelve, and at this price it remained until about 1885. In that year, by using the electric furnace, the Cowles brothers of Cleveland, Ohio, produced cheap alloys of aluminium. Others, by improving the electric processes, succeeded in making five hundred pounds of aluminium a day.

This was about 1886, but as soon as the electric processes of manufacture were applied to the metal its price was brought steadily downward, and within ten years the works at Niagara Falls were producing about ten thousand pounds a year. Its price in 1902 was about thirty cents a pound.

Electrically considered, though its resistance is greater than that of copper, yet for the same weight the resistance is the same. In regard to its use as a conductor, Tesla says: "It is cheaper to convey an electric current through aluminium wires than through copper wires." He believes that the aluminium industry will annihilate the copper industry and will pass on to a struggle for commercial supremacy with iron.

Which will prove conqueror depends upon whether the magnetic power of iron continues to make it indispensable in electric machinery. If these properties can be dispensed with, says Tesla, "iron will be done away with and all electric machinery will be manufactured of aluminium at prices ridiculously low. This would be a severe, if not a fatal blow, to iron."

We cannot refrain from quoting a few more words from Tesla's article entitled "The Problem of Increasing Human Energy," in *The Century Magazine* for June, 1900. "There can be no doubt," he says, "that the future belongs to aluminium, and that in times to come it will be the chief means of increasing human performance. I should estimate its civilizing potency at fully one hundred times that of iron. . . . We must remember that there is thirty times as much aluminium as iron in bulk available for the uses of man. It is more easily workable, it partakes of the character of a precious metal, its electric conductivity for a given weight is greater than that of any other metal, which alone is sufficient to make it one of the most important factors in future human progress. Its extreme lightness makes it far more easy to transport the objects manufactured." And this great gift to mankind may be credited solely to the use of electric energy, either in electrolysis or in the electric furnace.

The extension of telephony to include a commercial line from New York to Chicago was a notable event of the World's Fair year.

CHAPTER XXI

ELECTRIC WAVES AND RAYS

THE year 1894 was notable principally for the beginning of the experiments of Marconi in practical wireless telegraphy, experiments which to-day may be considered successful in adapting wireless telegraphy to practical use. This young Italian was born near Bologna. He was the first to perfect the appliances used in space telegraphy and the first to patent the application of the Hertzian waves to actual telegraphy.

It was also in 1894 that Professor Oliver Lodge, in demonstrating wireless telegraphy before the Royal Institution of London used the Branly coherer of iron filings in a glass tube in order to detect the waves and to make them close a circuit operating a bell. He improved the apparatus, by combining with it a so-called "tapper," a little hammer operated either by clockwork or electricity, that by striking the coherer restored the filings to the looser contact.

An advance of this year, 1894, in telephony was the centralizing of all the batteries in a single exchange for each telephone district, instead of employing separate batteries in the house of each subscriber.

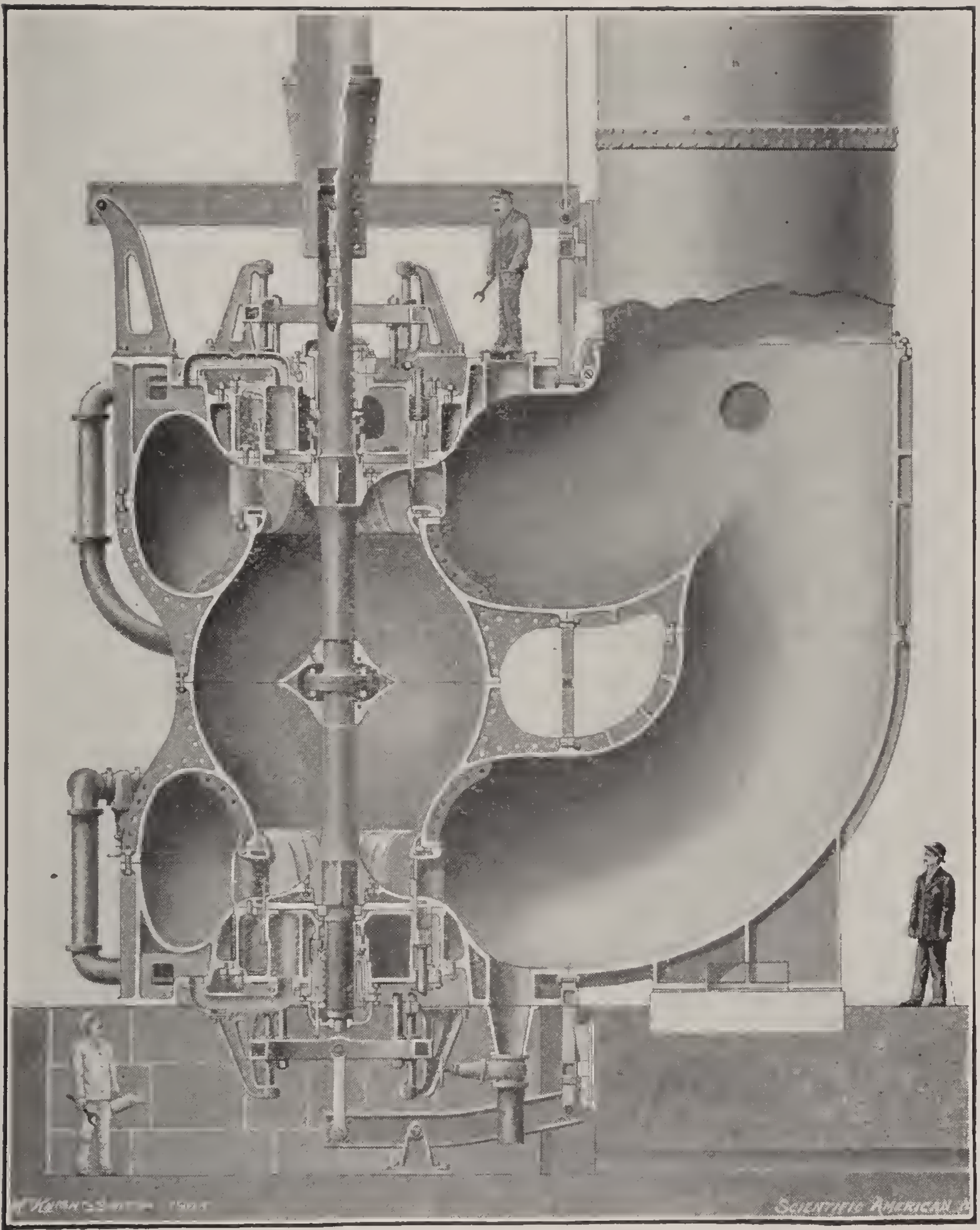
The year 1895 was rather a remarkable one in the history of electrical development. The great increase in electrical devices and competition of various companies in making them, had caused a fall of their prices, and this widely extended their use. It also attracted to the businesses relating to electricity a higher

class of talent and generally stimulated the science and art as commercial success naturally would do.

The World Almanac for 1896 declares that money in 1895 would buy nearly ten times the value in electrical supplies that the same money would have bought ten years before, and this with an improvement in quality. A third reason for the electrical prosperity was the increasing confidence of capitalists in the art. Fully fifty millions of dollars of new capital was this year devoted to electrical enterprises.

To take up the different fields in order — The telephone was greatly extended, though without any especially notable improvement. In telephony, the expiration of certain of the Bell Company patents brought many new competitors into the field. This naturally increased the number of exchanges and improved the service. In this year also was established a system of charging according to the use made of the instruments, instead of at a fixed rate. In New York the telephone circuits were entirely metallic — that is, wires were used both for the outgoing and incoming current instead of connecting lines to the earth.

In electric light no great novelty appeared, though much was expected from the inventions of Tesla — an expectation that was disappointed because of the destruction of the inventor's laboratory by fire. In the use of electric power the history of the world was one of general extension to various manufacturers, the installation of many electric elevators, and particularly of electric fans in large numbers. A device that found much use in mining was that of the chain-cutter, an endless chain provided with blades and



13,000 Horse-Power Turbine for the Electric Development Company, of Ontario, Ltd.
By courtesy of The Scientific American.

operated by an electric motor so as to bring the knives, or cutters, in contact with a vein of coal.

But the most important development of the year was in the transmission of power which resulted from a combination of dynamos with water-power driving water wheels, and thus generating electricity from the cheapest source of electric energy. The limit of distance for that time was thirty miles. The Niagara Falls Power Company of this year completed its great plant for the purpose of supplying practically unlimited power derived from the falls. It is estimated that the power available amounts to perhaps seven million horse-power.

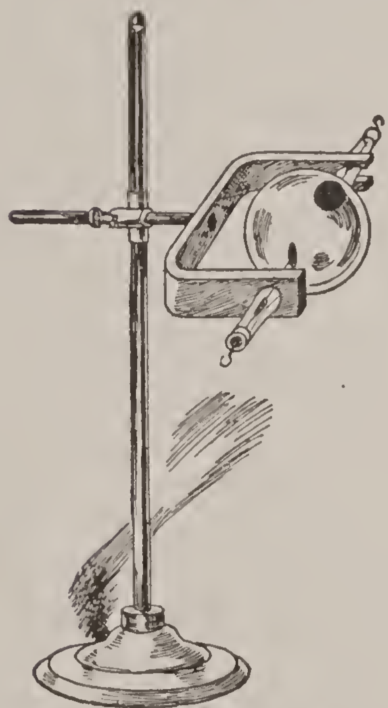
The method adopted for changing gravity energy of the falling water into electric currents may be generally described as follows: A canal was dug extending from the river about a mile above the falls. Parallel to this was a wheel-pit, 178½ feet deep and 425 feet long. This wheel-pit was connected by a tunnel with the river below the falls. In the wheel-pit were set up ten turbine wheels weighing a hundred and fifty thousand pounds each. The water entering the wheels from below tends to lift them and makes them run without friction so far as their weight is concerned. To the shaft of the turbines were connected alternating-current dynamos which yielded the current that, properly changed by transformers, could be conducted where desired and then retransformed to serviceable condition.

The electric railway came more and more into use during the year, in many cases superseding horse cars in entire cities and also showing signs of replacing even the steam locomotive upon shorter suburban lines.

The World Almanac, which gives an excellent summary of these facts, ends its article with this statement: "Taken altogether, electrical developments of 1895 have resulted in a vast increase in the convenience and economy with which many of the tasks necessary to comfortable existence may be accomplished."

But even that summary makes no reference whatever to probably the most important discovery of the year — the Roentgen or x-rays.

In 1895 Professor Roentgen of the University of Wurzburg announced the discovery of certain new rays of unknown nature which he named "x-rays" because they were an unknown quantity like x in algebra. His discovery came about while he was making experiments in passing the electric current through a glass tube which had been exhausted nearly to a vacuum, and in order that we may understand something of his work, we must recall certain studies upon the subject.



THE CROOKES TUBE, FOR PRODUCING THE ROENTGEN OR X-RAYS

When a glass tube is exhausted until the air pressure has been reduced to $\frac{1}{10000}$ of the usual pressure, and then a current is passed through wires fused into it, there are some striking appearances produced. A glow of light appears at the cathode wire (the negative or "outgo" wire), next to it is a dark space, and then a glowing space. The glass near the cathode also glows with a vivid phosphorescence. The cause

of these effects was studied by a number of experimenters from 1859 to 1879 and about the latter year was well explained by Sir William Crookes of England. The "cathode rays" were thought to be caused by something coming from the cathode, since a substance put in them caused a shadow on the opposite side of the tube, and this shadow also showed the path of the rays to be straight from the cathode surface. A concave cathode surface was found to concentrate the rays as a concave mirror concentrates light rays. These rays have a strong heating effect, and also act with mechanical force to push an obstacle from their path. Sir William Crookes caused them to push a little wheel with paddles along rails within the tube. They also cause the glass tube to show phosphorescence where they strike on it, and they make the air or other gas in the tube a conductor of electricity.

But, most important of all, the cathode rays were found to be turned from their path by an electric or magnetic field of force — acting as the electric current acts in the same circumstances. Hence arose the theory that the cathode rays were particles of gas negatively charged with electricity and repelled with great velocity from the cathode since it also was in the same electric condition. This was the view of the English. But the Germans saw no reason to believe there were moving particles in the cathode rays, considering them only ether waves.

Heinrich Hertz in 1892 strengthened the German view by showing that the rays would pass through gold leaf, which seemed hard to explain by the English theory. Lenard, an assistant to Hertz inserted a

bit of aluminium in the walls of the tube, and directing the rays upon this "window" brought them out of the tube, where they became known as "Lenard rays."

But then Professor J. J. Thomson showed in 1897 that the deflecting of the rays proved them probably to be particles negatively electrified or to carry a charge of electricity with them. Further experiments by the same brilliant philosopher *measured* the masses of these particles, their velocity, and the charges carried by them — and their ability to pass through subtances was explained. It was because of their minuteness and their almost inconceivable speed of motion. His experiments were carried on in England with the most elaborate care and are well worth the closest attention by students who wish to understand the modern theories of matter. But here we cannot enter fully into them, and must refer the reader to more technical books for the details and proofs of Thomson's conclusions. And for a most interesting account of the conclusions to which Thomson's experiments lead the reader cannot do better than to examine the lecture by Sir Oliver Lodge, delivered at Oxford in June, 1903. This lecture is published by the Clarendon Press and is reprinted in the Government Report of the Smithsonian Institution for 1903, to be found in the libraries.

In speaking of these experiments the lecturer declares that the researches may be said to constitute "the high-water mark of the world's experimental physics during the beginning of this century."

The conclusions drawn by Sir Oliver Lodge are that the so-called smallest possible material body, the

atom, has been shown to be divisible; that the so-called electrons can be separated from atoms, that the atom may possibly be built up of positive and negative electrons and *of nothing else.* These electrons are to be thought of as flying about inside the atom, forming a kind of cosmic or solar system of inconceivable minuteness and occupying an otherwise empty region of space which we call the atom, "as a few active soldiers might occupy a large territory, by incessant activity rather than by bodily numbers or bodily bulk." Whether the electron has a nucleus of matter within it is still doubtful.

This theory agrees with the claims always made by Crookes himself — that the matter in these tubes was in a *new* state, in a fourth state (1 solid, 2 liquid, 3 gaseous, 4 *new*), which he called "radiant matter."

It is a stream of these electrons — those charged negatively — that make up the cathode rays, and in investigating these cathode rays Professor Roentgen found that there was produced at the same time another kind of rays that were invisible, not deflected by a magnet, and yet would readily penetrate many solids opaque to ordinary light and solids that stopped the cathode rays.

In order to give an idea of the supposed relative size of these electrons compared with a single atom of hydrogen, we shall quote another paragraph from Sir Oliver Lodge, who said: "If we imagine an ordinary sized church to be an atom of hydrogen, the electrons constituting it will be represented by about seven hundred grains of sand, each the size of an ordinary full stop [a period], three hundred and fifty positive and three hundred and fifty negative, dashing in all

directions inside, or, according to Lord Kelvin, rotating with inconceivable velocity. . . . The extreme minuteness and sparseness of the electrons in the atom account for their penetration. Electrons will pass almost unobstructed through ordinary opaque bodies."

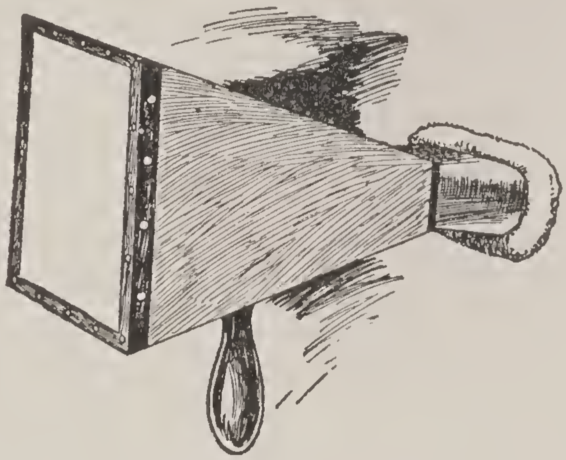
Professor Roentgen having covered a vacuum tube lighted by cathode rays with black paper, so that no visible rays appeared, these x-rays were not interrupted, but came out of the tube through the paper so as to illuminate and make phosphorescent a sheet of paper properly prepared with certain chemicals. This paper had been prepared for use with the cathode tube, and was accidentally near. The x-rays were subjected to a number of experiments and their properties ascertained. The most striking of these was their ability to affect the photographic plate while it was covered by the usual plate-holder, impassable by ordinary light.

By trying different substances in the rays, it was found possible to separate them into classes in regard to their transparency toward the new dark light. It was soon seen that a most valuable new agency had been discovered. Professor Roentgen believed that the rays were the so-called "longitudinal" rays of light whose existence had been conjectured by scientific men, notably by Lord Kelvin.

The meaning of longitudinal in this sense is that the rays are supposed to vibrate from and toward the source of x-rays rather than transversely across the path of the beam, as in ordinary light. Since bones are less transparent to these x-rays than is flesh, it was at once seen that the rays would enable a surgeon to photograph the bony structure through the flesh, and for this purpose they were early used.

The applications of the discovery have been too numerous to be easily mentioned here, extending from such uses as discovering false diamonds by their transparency being less than that of the real stones to the revealing of smuggled goods inside of closed boxes, which has been done in custom-houses.

In order to avoid the necessity of taking the photographs, in 1896 an Italian, Professor Salvioni, coated a screen with a phosphorescing compound, platino-cyanide of barium, and affixed to the screen a box and eye-piece so that the observer could look through the screen, the outer light being excluded. If a hand,



THE FLUOROSCOPE

for example, were interposed between the source of the x-rays and the screen, an observer looking at the screen could see upon it shadows of all substances that interfered with the transmission of the x-rays.

A similar "fluoroscope," or "fluorescent screen," as the apparatus is called was afterward made by Thomas A. Edison to view the shadows. It should be explained, however, that "shades" rather than shadows, is the right word, since nearly all substances are more or less traversed by the rays and hence the

rays are not often stopped entirely as in making a true shadow. Edison improved the fluoroscope by using calcium tungstate as the coating, which gave better results than the substance used by Salvioni. Other substances have since been used, and there have been many improvements in the machines for producing directing, and photographing these radiographs or "skiagraphs" cast by the new rays.

Professor Elihu Thomson discovered that the x-rays can pass through and act upon a mumber of photographic plates at once, giving multiplied images with one exposure. The action of these rays upon the human skin when allowed to affect it too long or too closely is at times harmful or even destructive, and this has led to the invention of means for directing, restraining or modifying its influence.

It was in 1895, also, that Nikola Tesla brought out his electric oscillator, a means for producing a rapid alternating electric current by a combination of the steam engine and the electric motor. Essentially, this apparatus consisted of an engine that plunged a piston into and withdrew it from, a coil, with enormous rapidity and thus caused in the coil alternations of electric potential that induced a current of great frequency. It was, in fact, an induction machine, the interrupter of which was a piston driven by steam.

So rapid was the development of the use of the x-ray in 1896 that there were ten firms engaged in supplying apparatus for producing the rays to hospitals, physicians and investigators. Such men as Edison and Tesla gave much of their time during the year to the improvement and study of devices connected with the new discovery.

In telegraphy an interesting feat occurred during the great electrical exhibition held in New York City in May, a cable message being dispatched around the world from one end of the building where the exhibition was held and received at the other. The transmitting operator was A. B. Chandler, president of the Postal Telegraph Company, and the message was received by Thomas A. Edison.

The telephone continued to increase in popular favor and was reduced in price and extended in the distance covered. For "all practical purposes the whole country east of the Mississippi River was one vast telephone exchange." The presidential election gave the telephone companies an excellent opportunity of demonstrating the swiftness and ready distribution of news by means of the telephone, giving the returns in this way to some twenty thousand people in private residences in New York City even before the results were known in the very towns from which the returns came. Generally speaking, the telephone news was half an hour in advance of the telegraph.

Another interesting exhibition of telephony was the setting up of a transmitter in the Cave of the Winds at Niagara from which the roar of the falls was brought within hearing of visitors to the electrical exhibition in New York City.

In electric lighting, a second globe was placed about arc lamps, a great advance in the art of arc-lighting. The second globe made the carbons last longer, improved the distribution of light, and also lessened danger from falling sparks. A new system of lighting by means of vacuum tubes excited by the alternating current to luminosity was devised and exhibited by Pro-

fessor D. McF. Moore, and has come into use especially for advertising purposes.

The use of electric power commercially continued to extend in all directions, and on the 16th of November electrical energy equaling one thousand horse-power was transmitted from the works at Niagara Falls to Buffalo, twenty-six miles away, and there used for driving street cars.

The means of transmission from the falls to the city limits was by bare copper wires insulated on porcelain. Then underground conduits brought the power into the city. In the electrical exhibition in New York a small model of the Niagara Falls works was put in operation by means of one-thirteenth of a horse-power transmitted over four hundred and fifty miles from the falls itself. The next longest previous transmission of power was about a hundred and ten miles.

In electric railways there was large increase in the number of roads operated and in their economy. A Chicago railroad claimed to save ten thousand dollars a month over the cost of steam power. Thus, although the year 1896, a presidential year, was the worst business year in the history of the industry, to quote from *The World Almanac*, there were many signs of steady progress.

In 1897 Edison announced the completion of his magnetic process for separating iron from its ore. This is done by crushing the ore to a finely-divided state, hoisting it to the top of a high building, and then allowing the crushed ore to fall in front of the poles of magnets. The attraction of the magnets draws the particles of iron toward them and they are thus caused to fall nearer to the magnets than the rest of the

powdered ores. A fence is so placed as to separate the iron from the waste product. This, like some others of Edison's inventions, illustrates no new principle, but is merely an ingenious man's adaptation of well known principles to commercial purposes. The idea of separating iron from the ore may not have been entirely new or the method original solely with Mr. Edison, but its application upon a commercial scale and its commercial success may be credited to him.

So far as telegraph and telephone were concerned, the chief event of importance was the removal of overhead wires from down town, New York, to underground conduits, a most desirable improvement made possible by the better knowledge of means for securing perfect insulation. There were no startling novelties introduced during 1897, the history of the year being one of generally increased improvement in the already well established industries and enterprises dependent upon electricity.

New York City saw the beginning of an electric cab service, a result due to the improvement of the storage battery. The storage battery system of propulsion is especially adapted to cab service, since these vehicles can always be within reach of electric stations from which they can obtain new batteries.

To the discovery by Dr. Carl von Welsbach that certain rare elements when brought to a state of incandescence gave out a very brilliant light we owe the gas mantles now so commonly seen in the Welsbach burner, a device that, according to Robert Kennedy Duncan in an article published in *Harper's Magazine* in August, 1906, was the salvation of the enormous gas industry.

In order to study these incandescent minerals, Welsbach had dipped a bit of cotton fabric in their solutions and afterward held it in the flame of a Bunsen burner. "It did increase the incandescence," says Professor Duncan, "but it did more; the cotton burned away leaving a skeleton fabric made of the oxides of the elements, and this skeleton glowed with a brilliancy and a beauty that were astonishing." From this accident came the invention of the Welsbach mantle. But these rare earths, as Professor Duncan puts it, were not only "sauce for the goose" in saving the gas industry, but "sauce for the gander" in improving electric lighting.

In 1897, Professor Nernst, of Göttingen, showed that while a filament made of these rare substances was at ordinary temperatures a non-conductor of electricity, when heated even by the burning of a match, their conductivity increased and kept on increasing. To quote again: "It is very like one of the Holland dams. So long as the dam is perfect the dam is safe — it is a non-conductor of water — but permit the smallest hole, no larger than a finger, upon which the water may work, and, shortly after, the resistance of the dam has broken down and the whole volume of the current washes through. The cold filament made of these earths offers an impenetrable resistance, but at 600° C. a little current passes. This makes the filament hotter, which allows more current to pass, which makes the filament still hotter, which permits still more current, which makes the filament hotter again, and so it builds itself up until it arrives at a semi-pasty condition when practically the whole of the current passes through, and it shines with a

very vivid and very beautiful incandescence. This is the basis of the Nernst lamp."

But the full development of the lamp, and of similar lamps using rare elements, did not take place for several years.

The year 1898 saw a very marked improvement in the application of electricity to street railways and other forms of traction. The electric cab system had proved successful, street railways were being electrically equipped everywhere, and the long distance railways were making inquiries as to the relative advantages of steam and electricity and in some cases had decided to equip their lines for the latter power.

This year of the Spanish War produced, of course, a sudden and enormous demand for electric devices. The coast of the United States was protected by thousands of submarine mines and by extra systems of communication, all of which required thousands of miles of wire, and there was a similar sudden demand for trained men capable of supervising governmental electric installations. This demand led to the formation of a corps of Volunteer Engineers, mainly of electricians, who under pressure showed themselves rapid and accurate workmen.

The medical department of the Army called for x-ray machines in large mumbers; the Navy, already fitted with electrical devices for turning the turrets of warships, for hoisting ammunition, for lighting, signaling, and the operation of the great search-lights, also increased the demand for electrical work and supplies. So that the year was one of great profit and rapid progress in electrical industries.

Another secondary effect of the war was the stimula-

tion of the telegraphic service, some of the largest newspapers expending from one thousand to fifteen hundred dollars a day for despatches. Meanwhile a sympathetic increasing interest in electrical industries brought about a very successful electrical exhibition at Madison Square, New York, and here, as well as at Omaha, Pittsburg, Philadelphia and Chicago, where various exhibitions were held, the electric light was applied in many novel and beautiful ways to form decorations.

A THIRTY-INCH SEARCHLIGHT AT WORK

The application of the search-light to warfare had proved its enormous value, the blockade of Cervera's fleet at Santiago being made effective by the concentration of searchlights on the harbor entrance, which not only revealed every movement of the enemy, but also blinded the eyes of Spanish watchers to the proceedings of the American fleet.

As a defense against torpedo craft the search-light in combination with small rapid-fire guns proved entirely effective, the efforts of the Spanish boats to approach the Americans being completely futile.

Equally successful was the transmission of power on board the warships from central power installations on shipboard, and the various applications to mechanical work — to guns, pumps, doors of compartments, and so on; the great advantage of the electric power for all such purposes lying in the fact that if the wires of communication are cut, they are readily repaired, and at the same time their cutting produces no damage to speak of as contrasted with the terrible results caused by the bursting of pipes carrying hot steam. In signaling, the search-light, combined with the wigwag system, proved most useful and was applicable to great distances.

Turning to the triumphs of peace, it may be recorded that the amount of power transmitted from Niagara Falls rose to sixty thousand horse-power, and the growth of power plants was especially marked in the newer parts of country, in the West, where their value depended largely upon the fact that water-power was often available at considerable distance from the manufacturing or transporting centres where it was needed.

The telephone, with 270,000 subscribers and four hundred and twenty thousand miles of wire, was improved by the adoption of the new switchboard, wherein the lighting of tiny glow-lights warned the operators whenever a subscriber was through with his communication. In distance the record was twenty-six hundred miles, from Austin, Texas, to Bangor, Maine.

There were also three advances in the theoretical study of electrical communication, due respectively to Marconi, Tesla, and the late Professor Rowland of Johns Hopkins University. Marconi, having erected

vertical wires from eighty to a hundred feet high, by the use of an induction coil giving a spark ten inches in length, was able to transmit waves through space to a distance at first of forty miles, and afterward, by using higher vertical wires, of two hundred and eighty miles over water. These waves were received by means of the Branly and Lodge coherer, thus operating receiving instruments. We shall describe this system a little later, after speaking of the other two methods of communication.

Tesla announced the result of certain researches proving that several miles upward the air, becoming rarefied, ceased to give great electrical resistance and became an excellent conductor. This is already applied to a system of telegraphing by means of balloons. Sending up two balloons at a distance from one another, each about five miles high, he transmitted a current through a wire to one of the balloons, where, by means of transformers the current was made one of high potential capable of sending waves through these conducting layers of upper air. These waves being received by the other balloon, were again transformed by instruments which it carried, and transmitted by a wire to the earth, where they operated a telegraph receiver.

Tesla during the same year, announced and illustrated by a model, the possibility of building a self-operated vessel which he named the "telautomaton." A storage battery placed within furnished motive power. A propeller driven by a motor enabled it to go in any direction when steered by a little motor operating the rudder. The control of his boat was accomplished by an electric circuit operated by electric waves sent

through space, the circuit being tuned so as to respond only to certain waves of determined length. These waves were furnished by his electric oscillator. This tuning is accomplished by attaching plates of metal to the discharging points of an induction-coil — the size of the plates governing their vibration.

Tesla's purpose in making his model was to show that warfare might be carried on by means of automatic vessels, or rather mechanisms, while the operators remained far from the danger zone.

In speaking of his invention in *The Century Magazine* for June, 1900, Tesla says: "There is virtually no restriction as to the amount of explosive which can be carried or as to the distance at which it can strike, and failure is almost impossible. . . . Its advent introduces into warfare an element which never existed before — a fighting machine without men as a means of attack and defense." Of course there has been no public application of this principle upon a large scale.

Professor Rowland's system of telegraphy was an improvement of what is known as the synchronous system — which has been tried in various forms by numerous inventors. The general principle underlying it may readily be explained.

Suppose a conducting wire to be extended from station A to station B. At the station A end of this wire is a revolving wheel against the side of which the wire touches. Upon the wheel are a number of segments radiating from the centre. As the wheel revolves the conducting wire touches one of these at a time, then passes on to the next, and so on around the circumference. On the opposite side of the wheel

are as many wires as there are segments, each arranged so as to touch only its own segment and none of the others. A similar arrangement is at the other end of the line at station B. If the two wheels are turned at the same rate so as to make the same segments touch the conducting wire between stations at the same time, it is easy to see that the wheels will connect each one of the pairs of wires successively with the conducting wire, A with A, B with B, and so on. Consequently the conducting wire becomes a part of each pair of wires in turn, completing their circuits. If an operator sends an electric impulse over his wire, it will be conducted to the other station and received by the *corresponding* wire at the instant when the two wheels cause the conducting wire to join this pair.

If, now, the wheels revolve so as to turn completely round once or more during the time an operator is holding down a key, every touch of a key will send an impulse over the conducting wire. It will be seen that, in theory, it is quite possible to use a single wire thus successively for a large number of messages, since it is easy to revolve the wheel fast enough so that it will make a single turn or more during the depression of a key.

Unfortunately there occur certain practical difficulties in applying the system to use, and though these have been to a certain extent overcome by a number of systems, and the multiplex system has been put to good use, it has never proved in all respects a successful competitor with its rivals in practical telegraphy. One of these difficulties is that of assuring exact harmony in the revolving of the wheels, especially at high

speeds. A second difficulty consists in the slowness of getting rid of previous electric currents in the conducting wire. If the messages follow one another very rapidly over this wire there is danger of previous messages interfering with later ones because the electric charge has not been cleared from the conducting wire.

A system of this sort used in Great Britain is known as the Delany system. It controls the motion of the revolving wheels, insuring a uniform rate, by electric motors at each station, these being governed by tuning-forks or vibrating reeds. In the Delany wheel there are eighty-four segments, insulated from one another, and the connection with the conducting wire is by means of a trailer which rests on the wheel. The wheel makes three revolutions a second, and consequently each segment touches the trailer three times a second. But to secure more frequent contact, more than one segment is connected with each pair of wires or lines through which the telegraphy is to be accomplished. Thus, to send six messages by the same wire, six segments are put into communication with the same pair of wires; consequently, at each revolution, this pair of wires is made to connect with the main conducting wire thirty-six times a second. The five other pairs of wires may also have six segments apiece, making thirty-six segments used for transmission in the six lines.

Another thirty-six segments in the same way are connected to the six different pairs of wires, using altogether seventy-two out of the eighty-four segments to connect the six stations at each end, each station thus being provided, thirty-six times a second, with a com-

plete transmission circuit, and also with a complete receiving circuit thirty-six times a second.

To make an ordinary dot in telegraphy takes about one-twelfth of a second, and during that time the revolving wheel (or the revolving trailer, for it makes no difference which revolves) will have connected the transmitter three times with the main line, each of these connections being independent of those given to the other operators at their six desks. The remaining segments, those not used for telegraphy, operate the mechanical devices that keep the two wheels or two trailers revolving synchronously, or at a uniform rate.

This system, invented by P. B. Delany, an improvement of earlier forms, is used in Great Britain.

Professor Rowland's system was announced by him to be capable of transmitting twelve messages each way at once, but its latest form transmits four in each direction at the same time. He used two cylinders bearing segments connected, like those in the Delany system, with separate pairs of wires, and the main principle is very similar. In brief, the general principle is simply to place a conducting wire successively between a pair of wires, and then between a second pair and a third pair, and so on, connecting each pair only for an instant and then being moved to the next.

Another system of multiplex telegraphy, that has not been hitherto explained, operates by means of tuned receivers. Over a single wire are sent, from tuned transmitters, a number of electric waves vibrating at different rates. At the receiving station are a number of ribbons of steel, each tuned, like the strings of a

musical instrument, to vibrate only under the influence of a particular note. When the composite musical tone arrives on the main wire each ribbon responds only to the vibrations to which it has been tuned, and the ribbon, when vibrated, actuates a receiving instrument. This has not been described because it has not come into extended commercial use, owing to the practical difficulties in its operation, and the space we can give to each of the later applications of electricity will not admit of noticing more than a few important and practical systems.

In speaking of the Marconi system of wireless telegraphy, while we must give to the Italian inventor all due credit for the devising and putting into practical shape of the system now so generally used, it should be recorded in every account of the art that the first wireless telegraphic communication was made by Professor Popoff, of Russia, who, in April, 1895, described to the Russian Physical Society a practical system. The production of the waves was by the same method used by Hertz, namely, an induction coil that produced sparks between two ball conductors and thereby caused electrical waves to be propagated in all directions about the instrument. Professor Popoff's receiver consisted of a vertical wire connected with a coherer which, in turn, was connected with the earth and also with a local circuit at the receiving station. This local circuit included a voltaic battery that operated an electro-magnet, and this moved a relay lever. The coherer was the ordinary tube of metal filings. When an electrical wave caused the filings to cohere, a current passed from the battery, operated the relay, and caused the closing of a circuit

containing a battery. This battery operates a receiving key, at the same time ringing an electric bell, and also with the same hammer striking the tube of iron filings and shaking them apart so that they are ready for another impulse.

The Popoff apparatus was not entirely perfected, but it will be seen that since it existed as far back as 1895, the essentials of the system were then understood.

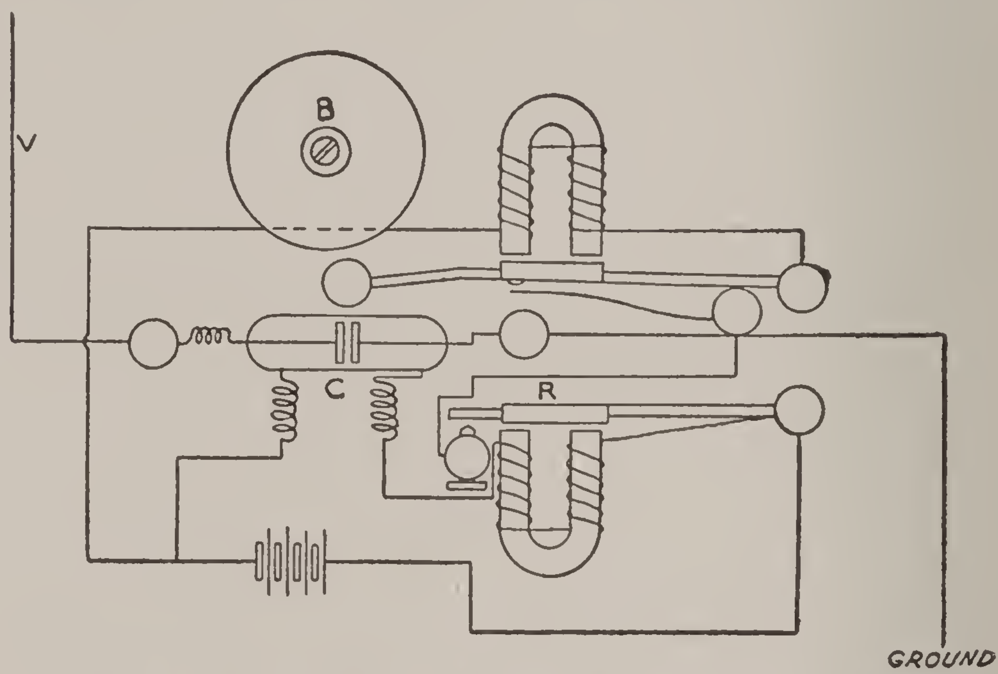


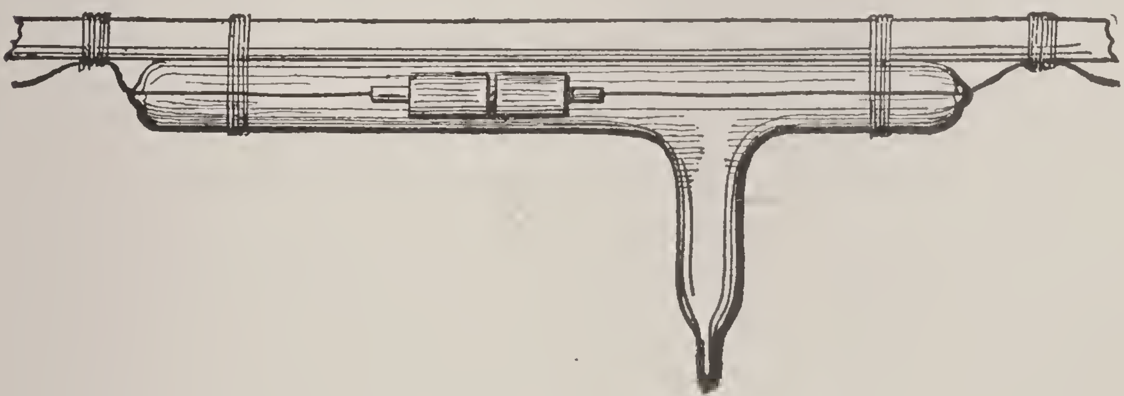
DIAGRAM OF THE POPOFF WIRELESS TELEGRAPH RECEIVER

A vertical "exploring" wire V is connected with the ground through the coherer C, which in turn is connected with a battery circuit and a relay R. This relay closes the circuit of another battery, not shown in this diagram, which is connected with a bell B and with the recording instrument. When the coherer is influenced it closes the latter circuit, actuates the recorder, and thus makes a record. The bell at the same time taps the coherer-tube, and thus breaks the circuit of the coherer by causing the filings which compose its filling to fall apart.

Marconi's system was completed, in its first form, in March, 1897. Professor Houston points out the resemblance between the Popoff and Marconi systems, but declares that Marconi was probably ignorant of what Popoff had already accomplished.

Marconi's system did not differ essentially from the other forms, being only an induction coil that pro-

duced sparks. His receiver used an improved coherer, being a glass tube closed by two pieces of silver only one-twenty-fifth of an inch apart, between which were pure nickel filings with a slight addition, four per cent. of silver filings. A little mercury was mixed with them to increase their sensitiveness. In this coherer tube a moderately high vacuum is produced, an improvement due to Sir Oliver Lodge. This coherer is in a circuit with a voltaic cell which operates a telegraph relay instrument; and this, in turn, is in a second circuit with a larger battery operating a recording apparatus and an electro-magnetic bell. The action of both trans-



MARCONI'S COHERER

mitter and receiver was similar in principle to those of Popoff, but Marconi added a most valuable feature in providing a high vertical wire at the transmitting end of the line, whereas Popoff had used the high wire only at the receiving end.

Another improvement introduced in the Marconi apparatus was two so-called choking-coils used in the first receiving circuit to prevent the waste of the electro-magnetic waves in parts of the apparatus where they are not a help to the action. The choking-coil is only a finely wound electro-magnet, which,

when in a circuit traversed by an alternating current, opposes to the passage of currents induced currents of the opposite kind, thus helping to confine the original current to certain parts of the circuit.

The theory by which the "snapping off" of electric waves into space is explained is an exceedingly complicated one, but the general idea we may give.

It is supposed that as electric force is sent into the two sparking rods of the oscillator there are formed, in the space round about these rods, lines of electric force that are likened in shape to half hoops of spring steel. These hoop-like strains of electric force lengthen and flatten out in shape as more electric energy is conveyed to the rods and are thereby stretched, just as a spring of the same shape would be stretched if flattened. When the electric force in one rod has reached an intensity enabling it to leap the space from one ball to the other, overcoming the air-gap resistance, this strain is suddenly relieved. The flattened hoops of electric force then suddenly contract into circular form. But their ends of opposite polarity cannot pass one another, and as the portions of the curves furthest from the rod have contracted more slowly than these ends, the electric wave is "snapped off" from the rod in circular form, revolving upon itself after the manner of a smoke ring, and so travels off into space, growing larger and larger just as a blown smoke-ring does.

Following these lines of electric strain come other lines of magnetic strain, which, however, run round the rods instead of along their lengths. These magnetic lines are said to be the result of the breaking of the electric lines of force, and they too reach their

maximum, then collapse and are detached. These processes repeat themselves in rapid alternation until that one oscillation ceases.

The rod is again charged, the strain grows, the spark passes; and the process is repeated with every charging and discharging of the rods.

This description, derived from the Encyclopedia Americana, is meant only to give a very general idea of the production of electric oscillations, or waves, in wireless telegraphy. Now, as to the reception of these same waves.

At the transmitting station stands a vertical wire. Theorists tell us that this may be considered as half of an oscillator, since the earth, a perfect conductor, takes the place of the other half and may be considered as containing a second wire corresponding to the first, as if the first were reflected in a mirror horizontally below it. From this circumstance this theory is known as the "reflecting" theory.

When waves going through space are intercepted by the vertical wire, we have a repetition of what takes place between the two rods of the oscillator. When the vertical wire is charged, lines of force are formed, as in the case of the rod of the oscillator, and in the same way are snapped off from it in waves that are propagated, it is believed, along the surface of the earth in concentric circles from the foot of the wire, following the contour of the surface. This theory explains why wireless telegraphy is not prevented from acting even when hills occur between the stations, since the waves are supposed to follow the contour of the earth near the surface of the ground, or the sea.

In the beginning of 1899 Marconi's system had been used successfully to transmit messages across the English Channel. He had already in England secured the backing of the British Telegraph department, being helped especially by the hearty aid of Sir W. H. Preece, chief electrician to the Post-office. Beginning on Salisbury Plain, between 1896 and 1898 messages were sent across the Bristol Channel, then for a distance of sixteen miles, and between South

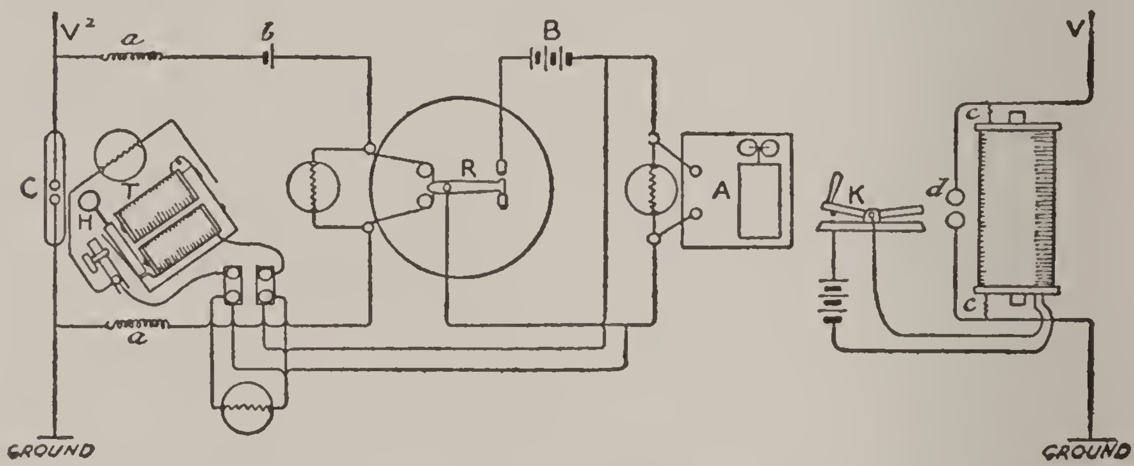


Diagram of the Marconi Transmitter and Receiver

At *d* are the spheres of the transmitter, connected, one to the "exploring" wire V, the other to the ground, as well as by *c c* to the secondary of the induction coil I, the key K being connected with the primary. The coherer C is connected, one pole to the ground, the other to the exploring wire V², and is also in circuit with the cell *b* and a relay actuating another circuit which works a trembler T, of which H is the hammer for decohering. When the waves pass from V² to the coherer the resistance drops by the coherence of the filings contained in the latter, and the current from *b* works the relay R, the "choking coils" *a a* between the coherer and the relay sending the waves through the coherer instead of the relay. The relay in turn causes the battery B to send its current through the tapper H and also through the recorder A.

Foreland lighthouse and the lightship twelve miles away.

To communicate across the channel he used a wire a hundred and fifty feet high and sent his messages thirty-two miles to a village on the French coast, two miles north of Boulogne. During the same year the system was tried successfully in the British Naval Maneuvres. Before the end of the year the signals

had been sent nearly a hundred miles. During this same year also Messrs. Pollak & Virlag adapted to wireless telegraphy the device of rapid transmission by means of a punched tape, as had already been done in so many forms of line telegraphy.

Late in 1899 the New York *Herald* engaged Marconi to come to this country for the purpose of reporting the international Yacht Races from a vessel that should follow the yachts and telegraph wireless messages to a yacht in the harbor connected by a cable with the city.

There were many experiments made during the year upon the availability of wireless telegraphy for signaling in the army or navy, but no final conclusion as to the best system was arrived at. The commercial progress made showed a continued rapid increase in the use of telephones, there being half a million subscribers; other applications of the electric light to decorative purposes at the time of the Dewey Parade in New York; and the entering of the electric light companies into the enterprise of supplying power in storage batteries that could be charged by the lighting plants, during those hours when their patrons did not call upon them for current.

In this year also there was a decided disposition on the part of manufacturers to substitute motors for pulleys and belting in driving manufacturing machines, and the makers of such machines were compelled to recognize the public demand by adopting them especially for use with motors. The building of the two new warships, *Kearsarge* and *Kentucky* showed the approval of electricity as a power, for both were electrically equipped throughout.

The great demand for copper wire largely increasing its price, the manufacturers of aluminium were enabled to enter into active competition, showing the beginning of the warfare between these two metals which Tesla had predicted. For city use storage batteries were much used in electro-automobiles, since the gasoline engine was not yet so far improved as to be a dangerous competitor. The progress of electrical railways may be briefly noted in the statement that by the end of 1899 there were nine hundred and fifty in the United States.

The year 1900 was, in general, merely a time of further increase along the same lines, together with certain improvements in all directions. There were at the end of the year three and a half billions of dollars invested in electrical enterprises. The extending of cables and telegraph lines continued throughout the world, new territory being constantly equipped, and the field of the electrical railway also continued to extend, being marked especially by the attempt to utilize the very much higher speed possible with electricity as a motive power. Among such devices was a plan for a mono-railroad on the "Behr System," — a road capable of making a hundred and ten miles an hour. Yet the motive power is said to be safely controlled by devices for switching the motive power into dynamos which apply brakes, and thus use the motive power itself to check too great speed.

The investigations as to the value of x-rays comprehended their application as a means of fighting diseases coming from germs. The results in tuberculosis were not favorable, but in certain skin diseases, such as lupus especially, the therapeutic effects were excellent.

Other rays than the x-rays had been discovered since, among them being the Becquerel rays, and these continued to be investigated. The names of Professor Gauss and Professor Clerk Maxwell were in this year honored by the International Electric Congress at Paris, the "Gauss" and "Maxwell" being decided upon as the units respectively of magnetic field and magnetic flux.

The nineteenth century ended with the entry of electricity into nearly all, if not all, the fields it has since occupied, and it hardly needed any great power of prophecy to foresee that as the force was more thoroughly studied and even better means of application devised, it would be likely to supersede in the service of man nearly every other force or energy. In delicacy, in power, in portability, in neatness or in exactness of application, it had already demonstrated its power to rival nearly every other agency controllable by man. It was demonstrated beforehand that our own century, the twentieth, must be distinguished as the Age of Electricity, and the rapidity of human progress is certain to be stimulated as never before by the possession of this agency and the control of its manifestations as a means of detecting, of measuring, and of governing, the substances and forces of nature.

CHAPTER XXII

ELECTRICITY IN THE TWENTIETH CENTURY

The year beginning the twentieth century was notable both practically and theoretically — that is, electricity was developed not only in business ways but as a science. As a business its growth aided what social philosophers call the "centrifugal" movement of the community; it helped to counteract the tendency to gather in large groups — in cities. For the extension of the telephone, the transmission of power by wire, and the lighting of small places, made business in smaller towns easier and more profitable, while living in remote places became more agreeable.

The electric automobile in this year showed itself capable of high speed, covering a mile in sixty-three seconds; and Edison, always quick to foresee electrical requirements, brought out an improved storage battery, the elements being nickel and iron. But though this form of cell is light and lasting, not injured by changes in conditions of use and simple in chemical action, the lead cell seems as yet to be preferred.

The telephone or telegraph "switch-board" has not yet been described. The theory of it is simple. Imagine six lines to enter an office. Suppose we fasten three of them parallel to a board; and then the other three, also parallel, cross them at right angles, but are on the *back* of the board. There is now no connection between them. Then we bore holes through the board where the wires would cross if they were on the same sur-

face. If now a plug of some conducting material be put into any of the holes, it will connect two, and only two of the wires, and each hole will connect a different couple. Any two wires not in use already may be connected without interfering with any other two. The commercial switch-board in improved form is based on this principle, for telegraph and telephone lines and other purposes.

The use of arc and incandescent lamps greatly increased, and a device for using only a small part of the current, or switching the current into large or small filaments or into one or two at a time as desired, was introduced, so that a lamp could be turned up or down.

The Pan-American Fair at Buffalo surpassed all previous attempts at electric illumination, the great success of the fair being its enormous electric tower in front of which was a cascade capable of the most marvelous effects of lighting, by means of electric lights that threw prismatic hues into the waterfalls. The exhibition in the building devoted to the arts dependent on electricity was declared to be the finest ever held.

An important step in electro chemistry was the improvement of the process of producing nitrogen compounds by bringing about the union of nitrogen and oxygen in the presence of electric arcs. As the nitrogen of the atmosphere is inexhaustible, and as soils are exhausted mainly by the removal of nitrogen and its compounds, there is hardly any process more important to the life of mankind than methods of separating the nitrogen of the atmosphere readily and cheaply. If this could be done, nitrogen could be put back into the coil, and the food problem would be solved, so far as productiveness is concerned.

In this year also, Professor Pupin, of Columbia College, a pupil of the German von Helmholtz, sold to the Bell Telephone Company his devices for an electrical relay for increasing the distance submarine cables would transmit the telephone vibrations. Essentially the invention consisted in introducing induction coils in the cable, so as to strengthen the vibrations.

The progress in wireless telegraphy continued, most of the transatlantic liners adopting the apparatus, and a station being installed out at sea upon the Nantucket Lightship. A new era, too, was promised by the inventor Marconi who on December 12, 1901, received signals across the Atlantic Ocean. Landing at St. Johns, Newfoundland, on December 6th, with two assistants, Marconi prepared his apparatus. On the 10th he sent up a kite and then a balloon to raise the vertical wires but both were carried away. On the 12th a kite was raised about 400 feet, and all was ready to receive signals. Marconi had arranged that the "S" of the telegraph alphabet (. . .) should be sent at certain intervals every day at a fixed time, from Poldhu, Cornwall, England; and about half past twelve, the signals came — the three clicks were heard by means of a telephone-receiver.

A full and striking account of the occurrence was written by Ray Stannard Baker in *McClure's Magazine* for February, 1902. This article also explains the Marconi system, including the method of "tuning" a receiver to respond only to waves of a certain number of vibrations a second; and also calls attention to the comparative cheapness of transatlantic wireless telegraphy as compared with the cable — the wireless stations costing only one-twelfth the amount necessary to lay a cable,

and the maintenance being incomparably cheaper. Though the article concludes with a suggestion that the cables may soon be made useless, that prophecy is hardly likely to be fulfilled. As the telegraph still finds uses despite the telephone, the cables will hardly be entirely superseded by the wireless.

The same development continued in 1902, the general increase being estimated at twenty per cent. over 1901. Following the example at Niagara, a company was organized to furnish 5,000 horse-power from the Sault Ste. Marie. In wireless telegraphy Marconi succeeded in transmitting a sentence across the Atlantic, while another system than his — the De Forest — was used in the United States Naval Maneuvres. In this system, instead of the coherer used in the earliest experiments of Marconi and others, the device for receiving the electrical waves is what is known as an "anticoherer." Two plugs of tin are inserted in a tube and between them is glycerine containing lead oxide. This forms an electrolytic device which causes particles of tin to be conveyed between electrodes ; but the electric waves act as interrupters of this action, and they increase the resistance of the circuit and cause disturbance that is heard by a telephone. The waves close the circuit in the coherer tube, and interrupt it in the anticoherer tube; but in either case the telephone or other device responds to the change of condition, and thus signals can be read.

There are other devices used for the same purpose, but only a brief explanation of them can be given. Marconi used for a time the Castelli coherer, in which a drop of mercury replaced iron filings, and acted as they did, to close more completely the gap between

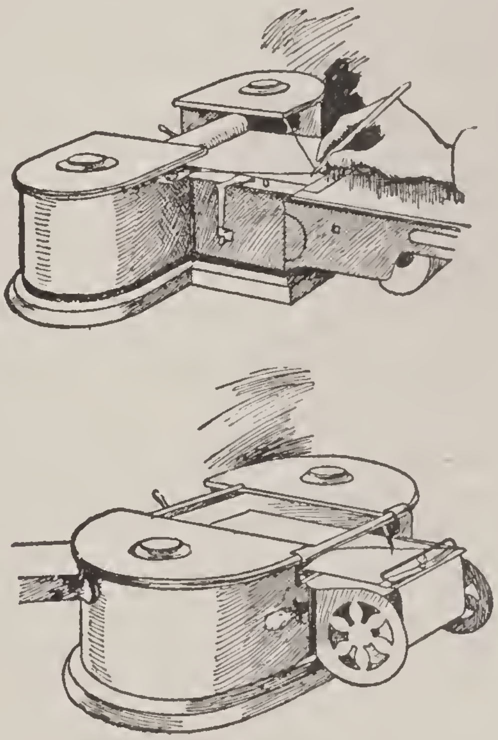
the conductors on the ends of the tube; but in his transatlantic experiments he used an "autocoherer" or magnetic detector, which was practically an induction coil, except that instead of the core of wires there was an endless wire rope running through the inner coil endwise. As this rope moved it touched the poles of two magnets. This made it change slowly in magnetism as parts of the rope approached and receded from the magnets. The electrical waves from the distant station change the electrical condition of the outer coil; this induces changes in the inner coil, and thus the magnetism of the rope is affected. To recognize these changes a telephone receiver is in circuit with the outer coil, and in this clicks are heard as the magnetism is changed. Such is the explanation given by William Maver, Jr., in an article reprinted from *Cassier's Magazine* in the Smithsonian Report for 1904.

It will be seen that many delicate means for detecting variations in electrical conductivity have been successfully used in wireless-telegraph receivers. The "barretter," for example, is based on the principle that a current heats a conductor, and this increases resistance. The telephone, as before, is used for making the results of the resistance audible.

It is a significant proof of the ability and ingenuity of scientific workers in the electrical arts that already there is a long list of systems of wireless telegraphy, and many rival inventors claiming credit for the various devices. The essential features of the art have, however, been here set forth; namely, the creation of electrical oscillations by coils, condensers, or dynamos, their reception in such a way as to change the con-

dition of an electrical current, and the perception of these changes by telephone or mechanical devices. But the main use of the system at present is for communication at sea.

Other improvements in telegraphy continued. A Pacific cable was laid — the longest in the world. The telautograph was adopted in this year by the United States War Department. This device, invented a number of years before, and exhibited at the Chicago



THE TELAUTOGRAPH

The upper plate represents the transmitter, the lower the receiving instrument.

Fair in 1893, consists essentially of mechanical apparatus so contrived that the motions of a writing instrument at one end of a line are repeated at the other, giving a facsimile of drawing or handwriting.

To understand this instrument, invented by Elisha-Gray, it must be remembered that any dot on a piece of paper can be reached if we are allowed to move in only two directions. Thus to reach the centre of the

page we have only to move upward or downward until opposite the centre, and then either right or left until the centre is reached. Now if we connect a pen with two telegraph wires, one of which responds to vertical and the other to horizontal motions we can cause these lines to move another pen both vertically and horizontally — that is, up and down or to and fro on the sheet of paper. The pen is attached to a rod that moves two plates so as to increase and decrease the resistance in the two wires by sliding these plates across a row of bars, including more or less of them in the line.

At the receiving station are two electro magnets that are strengthened or weakened in accordance with the current of the lines, and these move a pen that follows the motion of the sender's pen.

Another facsimile telegraph uses the received currents to move a mirror that reflects a ray of light on a slip of photographic paper, and thus records the motion of the pen in a photograph. Still a third form of facsimile telegraphy uses two cylinders, revolved at the same rate, at two distant stations. The paper upon one cylinder is marked whenever a current passes. The other cylinder has the message written in insulating ink on tin foil (a conductor). Upon the sending cylinder rests a point as the cylinder turns, and, being moved slowly along, touches each part of the cylinder surface in turn, following a spiral path. Whenever there is a written character, the current is interrupted by the insulating ink, and this lets the pencil at the receiving station make a mark on the receiving cylinder. Thus the whole message or design is gradually traced on the paper. A modifica-

tion of this method moves the sending point to and fro over a flat surface, but the principle is the same. Neither system is rapid, and neither is in extended use.

The history of the year 1902 in regard to commercial electrical arts records the progressive use of electricity in all fields so rapidly that only general statements can be made. American engineers began to find employment in all parts of the world, and the use of electricity for light power and traction ceased to be notable only because it was an every-day matter. Russia, Switzerland, Alaska, appear as fields for electrical enterprise, while the older established systems are enlarged, improved, and developed. Marconi had established thirty-seven stations by the end of 1902, and practically all great steamers carried wireless apparatus. In cities there were single buildings using 1,000 horse-power, and the railways had either adopted or were studying electrical methods of propulsion. In this latter field, traction, the use of the direct current for motors began to be laid aside in favor of alternating-currents, for the reason that the latter were better adapted to long distances and heavy traffic.

The advantages of the alternating currents consist in the readiness by which they may be transformed in frequency and thus transmitted, and then retransformed into any condition desired for use. They may be transmitted at low voltage, and then increased to high voltage; or transmitted as alternating and then commuted or transformed into direct current. The direct current requires heavy conductors, which are expensive, and so makes a number of power-stations neces-

sary. But these are engineering questions, and principally concern experts. The same remark will apply also to the questions of the use of the various phases of current for different purposes. And as to these latter years in the genealogy of "Father Amber," we must perforce admit that the branches of the family have grown to numbers and varieties that would require a library for their discussion. The individuals we cannot know, but must content ourselves with assigning each to its branch.

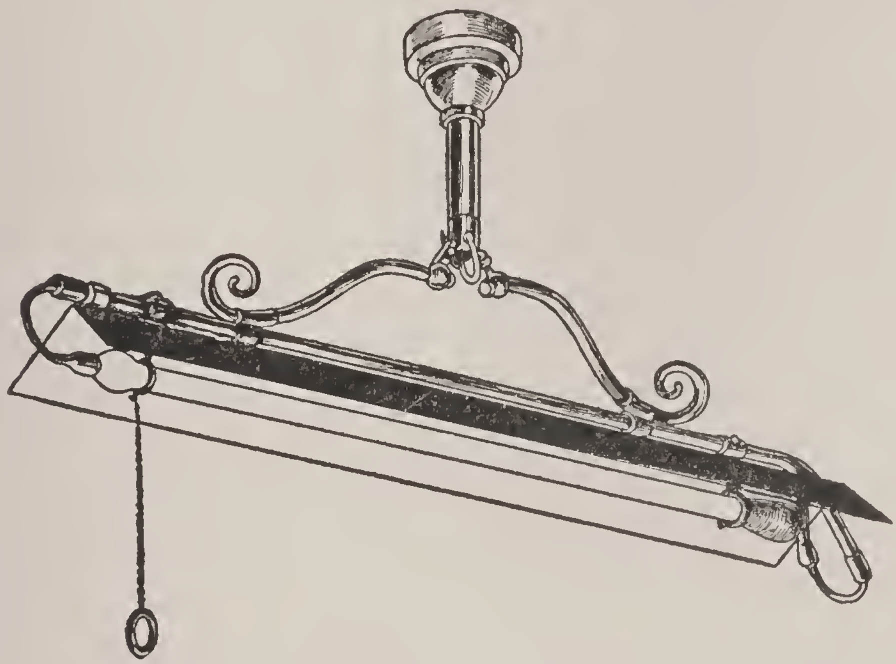
A glance over the field will help us to understand at least something of its subdivisions. To begin, there is first the theory of electricity — its nature, its origin, and its laws; and this raises the entire questions of matter, energy and life. Then comes the generation of electricity, by all methods — friction, light, heat, chemical action, magnetic fields, radiant matter. Thereafter we take up its applications to mechanics, to chemistry, to lighting, heating; and each of these gives rise to a whole art, and every art to its own great classes of machines, tools, and apparatus.

The amateur may know the general principles that underlie them all; he may know the particulars of a branch or two — but for the rest he must rely upon the technical books after he has acquired enough command of the terms to follow the printed explanations. The days of universal knowledge in one head are long past.

Passing over, therefore, the general statements showing the inevitable commercial progress in the various arts, and making no attempt to describe further the modifications of apparatus for wireless

telegraphy — many of which were directed toward removing the serious objection to the system, that its messages might be intercepted or interrupted, and were not secret — we will mention as significant events of the year the attempt to communicate by wireless waves with submarine vessels.

Experiments showed that the waves could not be depended upon to extend their influence further downward into the sea than rays of light would reach. Whether this was due to the supposed identity of the two forms of action or was a mere coincidence was



THE COOPER-HEWITT MERCURY VAPOR LAMP

not certain. The deadening effect of the water undoubtedly tended to make the vibrations slower and slower until they became too weak to affect the receiving apparatus.

Two new forms of electric lighting were brought to public notice in this year, the Cooper-Hewitt mercury light and the light known as the mercury arc, invented by Dr. Arons and Professor Steinmetz of Ger-

many. The Hewitt light, though cheap and brilliant, was open to the serious objection of its color, which, lacking the red rays, was unpleasant to the eye. This defect, however, does not affect its use for decorative purposes and for photography, the latter being a very favorable field, since the red rays are the least actinic and least valuable in photography.

The curative effect of the vibrations coming from electric lights of varying intensity was successfully applied by Dr. Finsen, of Denmark, who received one of the Nöbel prizes in recognition of his researches and practice. Roentgen also had been the recipient of one of these ten-thousand dollar prizes a year or two before. Professor Bedell, of Cornell, found that direct and alternating currents could be transmitted simultaneously over the same wire without interference, a discovery that promised, like most recent discoveries in the field of electricity, a wide development.

In fact, after the summary of the year's progress in general lines, the compiler of the electrical portion of the *Journal Almanac* remarks: "All the discoveries mentioned have an important bearing upon every possible use of electricity"—a sentence which is gratefully adopted as being a most succinct expression of the state of mind produced in one attempting to foresee the bearing of recent researches upon future electrical arts.

As illustrating the difficulty of guarding wireless telegraphic messages against interference, an amusing anecdote is quoted from an English source. Professor Fleming, an electrical engineer, had declared in a lecture that there was no interference of the waves. Four months later, while demonstrating the Marconi

system before the British Institution, he found the messages sent from the Poldhu Marconi station suddenly thrown into confusion. Professor Fleming, like a true Briton, wrote to *The Times* complaining of the interference, and was replied to by Professor Maskelyne, the scientific expert, who confessed that he had been tempted to make this practical answer to Professor Fleming's claim that the messages could not be interfered with.

He also pointed out that Fleming had claimed to use a *tuned* set of vibrations, and that he had been able to interrupt these by means of an untuned transmitter.

The year 1904 was notable for the general increase in the size and force of apparatus, machines of enormous capacity being practically used. The wireless telegraphy development was slow, and the United States Government remained undecided between rival systems. In atmospheric electricity investigations were followed up in the hope that by means of waves thrown into the air clouds or fogs could be condensed and rain precipitated.

In telephony the greatest improvement was the introduction of the automatic system of making connections between subscribers. The general principle underlying the very complicated apparatus that enables a subscriber to connect with a desired number bears some likeness to the principle underlying the telautograph. Just as in that apparatus the pencil can be made to touch a particular point by means of two motions, so the connection of a telephone can be made by a rotating dial to travel in various directions so as to rest upon a given point.

Suppose a table of numbers to be arranged upon a

large sheet, and at each number the connection with a line wire to be placed. To reach any one of these lines a device is adopted causing the connecting piece to travel vertically a certain number of steps and then horizontally along a line of numbers until it reaches the desired point.

In Professor Houston's book, "Electricity in Every-day Life," encyclopedic as it is, he declares these systems too complex to be described in the space at his command. A brief description of the apparatus may however be given.

Suppose a subscriber wishes to call 983. On his telephone is a dial containing the numbers from one to nine and then a cipher. Placing his finger in the hole marked nine, he turns the dial until it stops and then releases it. This causes a connection with the group of numbers beginning with 900. He then places his finger in the number eight, turns the dial as before, and by its return is connected with the *980* group. A similar action gives him the number three and its group, whereupon he presses a button that rings the bell of receiver 983.

The effect of turning the dial upon the subscriber's telephone is to send to the central exchange as many electrical impulses as the number he has touched. Thus, if he begins by putting his finger in the hole number nine, and turns the dial until it stops, and then lets go, the dial in returning to its place makes *nine* electrical connections and sends nine impulses of current to the central exchange.

Each of these impulses at the exchange raises a rod a single step upward. Upon this rod is a projection which by each step upward is brought opposite to a dif-

ferent range of metal rods. The first range contains the numbers up to ten, the second up to twenty, and so on. The second number touched turns the rod sideways or twists it, causing the projection to travel horizontally along the line of rods until it reaches the number desired. In the case supposed above, number eight. Now, if this last rod be divided into nine portions, a third movement, also upward, may be made to connect the subscriber's line with any portion of this rod.

The above description is not meant to be an exact statement of what occurs, but only shows the general principles.

In electro-chemistry there was notable progress as the importance of improved apparatus was shown, the many experiments made commercially enabling engineers to get better results by better designed apparatus — the electric furnace, for example.

In electric traction the advantages of using alternating currents, which could be transmitted over a small wire, tended to displace the third rail system of traction in certain places, since the advantage of using the third rail lay largely in its great capacity for direct current. The Subway in New York City, however, preferred the direct current, and was opened in October of 1904 with motor cars, each supplied with four motors of two hundred horse-power. An alternating current locomotive designed by Ward Leonard was successfully tested in Switzerland this year. The advantages of the alternating current comprise a quicker acceleration and therefore ability to handle heavier roads. Undoubtedly, however, in the development of the art the field will be divided between the two forms

of current in accordance with their special adaptability to particular needs.

The year 1905 saw an advance in electric lighting due to the employment of certain of the rarer elements the qualities of which adapted them especially to incandescent lighting. From one pound of *tantalum*, for instance, it is possible to construct twenty thousand lamps, and these have the great advantage that tantalum increases its resistance with increasing temperature, and, as it were, controls the lighting of itself. The stronger the current, the more the resistance; the weaker the current, the more of it passes; which results in a steady light. Other substances also are used, osmium, for example, each with advantages of its own.

A union that promises most important results in the production of power is that of the steam turbine-engine with dynamos. The turbine engines require but little floor space, and have an evenness of motion that makes them specially desirable for the dynamos that must be run at an even speed in order to produce currents of an even phase.

In telegraphy, the Barclay Typewriter System used typewriters at each end of the line, both for transmitting and receiving. This enabled the operator to make a typewritten original, and at the same time to have the message transmitted to a distant office and there taken down automatically by another typewriter. The putting together of the telegraph and the typewriter was not a remarkable achievement theoretically, but was a proof of mechanical ingenuity and of the certainty with which electrical mechanism could be made to act.

In brief, the principle was to cause the transmitting keys to transmit their motion to electro-magnets, each key operating a single magnet depressing the receiving typewriter key corresponding to the letter sent. The method of effecting this is very complex, but in general is similar to the device used for operating the printing wheel of a stock-ticker. A very excellent description of the system is given in the Encyclopedia Americana in the article "Telegraphy," where likewise all the modern systems are well described. Another equally clever device of similar nature causes the sending of the Morse signals to operate a machine that prints the message in ordinary letters.

CHAPTER XXIII

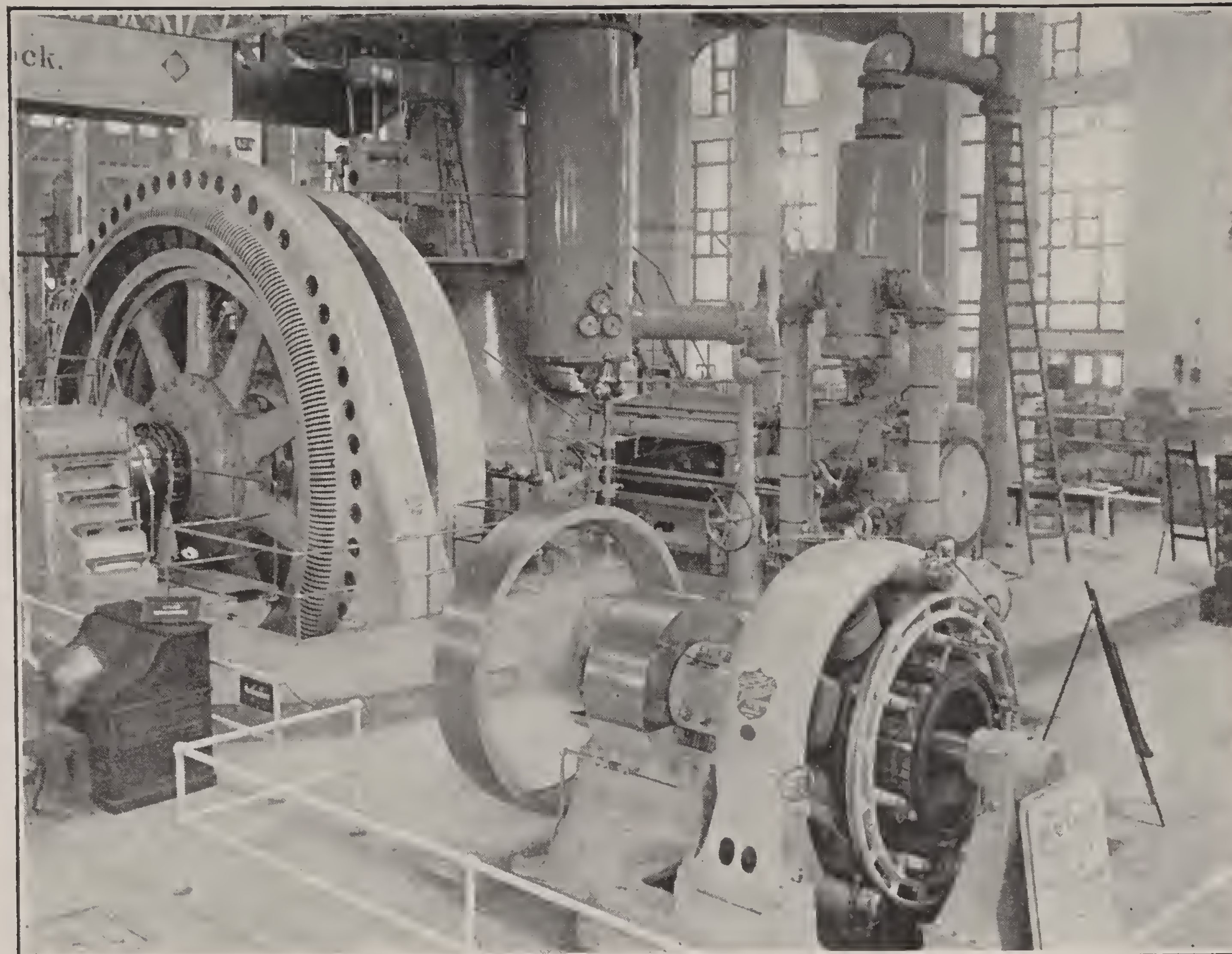
THE PRESENT AND THE FUTURE

THE author is almost tempted to make again the well worn excuse of the size of his subject, and he repeats it only as a warning that in speaking of the future not much that is definite can be said. From the authorities on the subject, however, certain conclusions may be adopted.

First, upon the improvement of electrical machinery.

It seems that there is very little margin for increasing the mere mechanical value of motors and dynamos. The present best device save certainly something more than nine-tenths of the energy that, theoretically, they should yield; consequently, improvements bringing out more than the extra tenth are impossible.

As regards batteries, there is no theoretical reason why the efficiency of storage batteries in proportion to their weight and durability should not be greatly increased. But this improvement might bring other disadvantages in regard to the rate at which power could be discharged. Upon the improvement of storage batteries rests the future of electric automobiles. As to the direct battery, the great problem of the future is to find some means of using the energy stored up in coal. Unless a battery using coal can be made, into which coal can be fed as readily as into a



THE "BULLOCK" GENERATOR (3,500 KILOWATTS) AND "ALLIS-CHALMERS," 5,000 HORSE-POWER ENGINE, WORLD'S FAIR, ST. LOUIS, U. S. A.

From stereograph, copyright by Underwood and Underwood, N. Y.

fire, the prospects for the coal battery are not bright. The problem is being worked upon by many inventors.

Another desirable achievement is the production of light without heat, for at present the greater part of the energy used in lighting goes into heat and therefore is wasted. In this case the margin for improvement is great, since the loss of energy when turned into light varies from ninety-eight per cent. to about ninety.

In regard to the application of electricity to the solving of mechanical problems we can only suggest that there is no mechanical motion to which electricity cannot be applied, and therefore we may expect the field continually to enlarge. The cheaper production of electricity from natural powers will make its use more general in all fields of industry.

A recent discovery announced by Nikola Tesla during the year is that the capacity of conductors varies according to a number of conditions and cannot be considered as constant. He finds that the degree of elevation above the ground, the season of the year, the time of day, have a by no means small effect upon the capacity of conductors. And he points out that some of the laws he has discovered may enable us to make instruments that will register, for instance, the altitude of places and some of the other particulars that vary the capacity of conductors. These variations of capacity may become theoretically important.

The improvement of the telegraph has been enormous during its short lifetime, but it is not yet possible

to accomplish completely two desired ends. One is the sending of telegrams with great rapidity during the hours when they are most numerous without the need of employing an apparatus which is too expensive for the transmission of the average number of messages during the whole twenty-four hours.

In the telephone — while wireless telephony is possible, it is by no means well advanced. There is apparently no impossibility in achieving the telephoning by tuned waves, so that one person can communicate with another regardless of locality. This result is of course far in the future.

A recent invention, the "telegraphone," enables the owner of a telephone to have any message that may be spoken into his receiver recorded in such form that he can repeat it exactly as it was transmitted in his absence. The same principle that records the telephone vibrations has also, I believe, been used to record telegraphic messages.

It consists of a wire of mild steel arranged so that the movement of a telephone receiver's diaphragm impresses upon the steel varying amounts of magnetism — the amounts depending upon the nearness of approach of the diaphragm of the telephone. The wire is caused to pass from one winding reel to another close to the vibrating diaphragm, and receives magnetic impressions that persist for a considerable time; exactly how long I do not know.

Upon reversing the motion of the coils the magnetization of different parts of the wire attracts the telephone receiver diaphragm, so that its motion is reproduced, the vibrations that made the magnetic forces are repeated, and the telephone repeats the message.

It is evident that the strength of these magnetic impressions could easily be increased by using a small permanent magnet to be moved by the diaphragm, and very likely this is done by the inventor. In a word, the invention is a "recording-telephone" that translates its diaphragm movements into varying magnetic fields in the wire, and so the telephone repeats the message.

The transmitting of pictures by telegraph is yet in its infancy. The method of sending designs a point at a time is much too slow. The methods of transmitting the points to a large surface simultaneously require far too many wires, and yet it is too early to be certain that a photograph of a reflected scene will not one day be transmitted by multiple current over a single wire.

As regards wireless telegraphy, we have already pointed out that the much desired improvements are in securing secrecy of messages, preventing interference with transmitted waves, and extending the space covered. The use of electricity in recording and reporting weather is already wide-spread, but it is possible that the future will give us methods by which we may to some extent control the weather, by causing moisture to be gathered into drops, and to fall in rain, at least over a limited area.

In the application of electrical power there are many fields yet unfilled. Charles Wilson Price in a recent article points out that portable electric power upon self-driven engines should be available for brief times and in remote districts; and of course the application of electricity to airships is eminently desirable. Electro-chemistry is one of the youngest of

our sciences and will be sure to advance directly in proportion to the cheapening of electrical power and its better application in the form of heat and other manifestations. The reign of the steam locomotive has lasted only about seventy-five years, and we are at the very infancy of electrical traction. It is therefore not unreasonable to expect the greatest practical developments in this field. Engineers predict the use of high tension currents transformed by *apparatus carried on the locomotives themselves*, as a solution of electric traction problems.

The life of electrical machinery compares most favorably with that of machines dependent upon steam-power. Not only do the electrical appliances last longer, but they are worth more as material after their active life is finished. As to the capability of applying natural forces to electricity, the field has hardly yet been entered except in the case of a few of our greatest rivers and waterfalls. It is not unreasonable to expect not only the use of water power everywhere, but the harnessing of the wind and, at a more distant date, perhaps the direct conversion of sunlight into the slower vibrations useful in electrical machinery. As to the transmission of power, engineers at present believe that there is a practical limit to its distance, since in order to extend the length of lines we must increase the tension of currents and thus approach the limits of economical insulation.

It is believed that there is no impossibility in securing enormously high speeds in electrically driven railways. In theory they are entirely possible, and the dangers and difficulties of high speed traction can undoubtedly be met by the ingenuity of inventors, since

the motors employ the same energy for control as for motive power.

The subject of wireless telegraphy has already been rather fully treated in proportion; but the future will see a great advance in all directions, and we may hope for the novelties of wireless transmission in the application of the waves to other uses than that of conveying intelligence — as foreshadowed by Tesla's "telautomaton," and in various projects for controlling aerial craft, exploding distant magazines, and so on.

As regards the questions relating to radium and similar radio-active substances, they can hardly be considered to come within the scope of a book on electricity, although the methods of electrical science must be used in studying atomic activity. The possibility of using the rays given off either primarily or secondarily, by various substances, to affect electrical devices by charging or discharging conductors, and so on, opens up a field wherein much speculation is possible; but it has not yet been particularly developed. The possibilities resulting from the study of radio-activity may include some method that will free mankind from their present slavery to coal as a cheap means of securing energy; but the experiments so far made have been merely minute laboratory proofs, or possibly only evidences, that the energy locked up in atoms may under certain circumstances be set free.

The telephone has opened to us one of the most promising fields of electrical science, but this has been evident from the general discussion of the subject already given. The instrument has led to a renewed study of the whole field of sound vibration and its

mastery. One of the most recent developments springing directly from the study of sound in connection with electricity is the new musical instrument invented by Dr. Cahill, of Holyoke, Massachusetts. In essence this invention uses a piano keyboard for the purpose of bringing to bear upon telephone lines all the power of electrical alternators, that is, machines producing alternate currents of any desired rapidity within certain broad limits. Electrical vibrations are produced directly by electrical action, and hence are free from the imperfection due to the material of instruments. Any character of musical tone may be thus exactly imitated, and when these tones are combined the resulting musical notes may be transmitted over any number of circuits, and turned into audible vibrations of the air.

The original machines cost enormously, one of the first built being worth two hundred thousand dollars and weighing two hundred tons. It is intended to establish a central station in New York to supply four or five thousand subscribers.

In order to point out remarkable applications possible in telephoning, we quote from a current magazine the statement that in Norway a hermetically sealed box is lowered into the water and contains a microphone. By means of a telephone sounds are heard from the submerged box, and these sounds differ according to the sort of fish approaching it, and the volume of sound gives a hint of the number of fish within hearing distance.

As we read the current news we shall see daily some new application of electrical devices. Thus, collected at random, I have before me items relating

to the steering of ships, to the supplying of oxygen to divers at great depths, depths from which they are hauled by an electric motor, an electrical method for testing the purity of mineral water by its differing resistance to the passage of currents. Next comes an account of the instruments of the weather service, wherein electricity plays by far the most prominent part. Following this we have a long article describing a delicate device for detecting the electrical condition of the human nerves in invalids, as a preliminary to treating them therapeutically by an electric current. The next article describes and pictures a great floating dock at Rotterdam, the entire operation of which — pumping of water, propulsion of the floating dock and the lighting of it — being done by electric devices. Another item tells how flour may be bleached by passing it through a high-voltage continuous-current arc. This is followed by a prophecy that household drudgery will become a thing of the past, owing to the numerous applications of heat, light, and power in the households supplied with electric current. There is even an apparently serious item describing a French invention by which mosquitoes or flies may be destroyed when alighting upon electrically charged wires; and from a recent scientific paper we have a description of an electromagnetic gun, designed to propel projectiles by means of coils of wire successively brought into circuit with a battery.

Strangely enough, I find with this an old newspaper clipping, taken at random from a scrap-book, describing the same invention. Unfortunately this scrap is not dated, but it is certainly a number of years earlier

than the invention described in *The Scientific American* of October 20, 1906.

From the same paper, a week later, comes an account of a motor designed to be run by electricity derived from the air or from thunder-clouds. As the ordinary motor is a dynamo reversed, so this invention may be described as a glass disk electric machine, multiplied and adapted to be run by electricity, instead of producing it. When this motor was connected with a vertical wire extending perhaps fifty feet into the air, it was found to rotate for some time before the occurrence of a storm.

A few more clippings are devoted to the study of electricity as contained in growing plants and to the culture of fruits by enveloping trees in electric light and applying currents to the roots. And we may end this unsystematic collection by referring to a recent item warning bee-keepers against allowing their hives to remain within the light of electric lamps at night, as one keeper of bees declared that his eager little workers refused to stop so long as the light was shining and literally worked themselves to death!

Undoubtedly the statements in some of these current accounts and anecdotes may be more or less distorted and exaggerated, but at least they will serve to show that there is no field of life in which we may not be met with some form of this omnipresent energy.

Any attempt to trace the history of this great science must be inadequate, but we have at least within brief compass caused the reader to traverse the whole story of the discovery, the investigation, and the application of electricity from the bit of rubbed

amber to the inquiry into the ultimate form of the atoms that make up matter. We have seen ignorant wonder and superstition pass through unsystematic to systematic study, and from uncertain theories to demonstration and practical proof that man can control the greatest of earthly forces. We have seen how the work of each investigator made easier the achievements of those who followed him, and have learned how what was a plaything of the curious has become the greatest agency within the command of mankind.

Among certain Buddhist philosophers there was an idea that greater power is entrusted to the individual, and to mankind in general, in direct proportion to the growth of spirituality — the ability to make right use of the power granted.

If this be true, the domain entrusted to man in the gift of the control over electrical energy is the most significant and the greatest in the history of mankind. It widens beyond our imagination the outlook of the race, and makes us dream of extending man's domain even beyond this earth itself.

FINIS

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